TECHNICAL UNIVRZITY OF LIBEREC
FACULTY OF TEXTILE ENGINEERING

DEVELOPMENT OF PROTECTIVE GLOVES WITH CENTRAL HEATING PAD

Diploma thesis

Study programme: N3106 – Textile Engineering

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TECHNICKÁ UNIVERZITA V LIBERCI
FAKULTA TEXTILNÍ

VÝVOJ OCHRANNÝCH RUKAVIC S CENTRÁLNÍ VYHŘÍVANOU VLOŽKOU

Diplomová práce

Studijní program: N3106 – Textilní inženýrství
Studijní obor: 3106T011 – Textilní a oděvní technologie
Autor práce: **Bc. Kristýna Pavluvčíková**
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ZADÁNÍ DIPLOMOVÉ PRÁCE

(PROJEKTU, UMĚLECKÉHO DÍLA, EMĚLECKÉHO VÝKONU)

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Finally I am grateful to my family and my friends for the support on the whole way and incented me to strive towards my goal.

ANOTACE

Teoretická část práce je věnována průzkumu trhu s vyhřívanými rukavicemi a jejich technologickému řešení. Na základě přiblížení principu biologického fungování krevního oběhu v horních končetinách je formulována hypotéza o možnostech vhodných efektivních úprav střihových řešení. Rešeršní část toto téma mapuje i z hlediska přenosů tepla a fyziologického komfortu. Experimentální část popisuje především postup při zhotovování navržených prototypů a jejich testování. Na závěr jsou veškeré poznatky zkonzultovány a zhodnoceny a navrženy úpravy vedoucí k vylepšení užitných vlastností.

KLÍČOVÁ SLOVA:

Rukavice, tepelný komfort, elektrický ohřev, tepelná vodivost, elektrická vodivost, elektrický odpor, sdílení tepla, krevní oběh, žilní systém, termokamera,

ANNOTATION

Theoretical part is devoted to research of contemporary market with heated gloves and the technological workmanships of the producers. Based on the analysis of the biological principle of blood circulation in the upper limbs is formulated hypothesis about the possibility of appropriate and effective shape modifications. The research part of the theses continues with terms of heat transfer and thermo physiological comfort. The experimental part describes the process of producing designed prototypes and their testing. At the end, all the reached results are discussed and evaluated. Finally there are suggestions on better modifications leading to improve requested properties

KEY WORDS:

Gloves, thermal comfort, electrical heating, thermal conductivity, electrical conductivity, electrical resistance, heat transfer, blood circulation, artery system. thermocamera

LIST OF ABBREVIATIONS:

P	. . .	electrical input power [W]
t	. . .	time [s]
T_{air}	. . .	temperature of air [°C]
T_{skin}	. . .	temperature of skin [°C]
U	. . .	electrical voltage [V]
I	. . .	electrical current [A]
R	. . .	electrical resistance [Ω]
R_{text}	. . .	resistance of textile layer [$m^2K\,W^{-1}$]
Q^*	. . .	Heat power loses [W]
λ	. . .	thermal conductivity [$W.m^{-1}K^{-1}$]
R_{bl}	. . .	thermal resistance of air boundary layer [$m^2K\,W^{-1}$]
α	. . .	heat transfer coefficient [$W.m^{-2}K^{-1}$]
v	. . .	air velocity [ms^{-1}],

CONTENT

INTRODUCTION:

In today's modern world is a life without electronic accessories and utilities unimaginable. In recent years becoming a part of usual textile products to increase their utility value. We speak about so-called wearable electronics. Function of electronics in textile industry start with the decorative effect on clothes and furniture, across the useful additional features of lighting or heating to irreplaceable monitoring role in medical care for seniors and infants in hospitals.

To be successful in textile industry competition does not mean just to know how to produce high quality goods any more. The important aspect is to be different from other similar producers and find a market gap. The product has to attract customer attention because of special design or added property which can meet new needs of present life.

One of the most popular “smart” products field is cloth items with heated facility. There are couples of companies around the world who try to come to the market with new, better and more durable item, as heated jackets, vests, socks, boots, and gloves and so on. The concrete technological solutions and market offer will be described in detail in research part of this thesis.

This diploma thesis seeks to come to this popular theme with a new idea of product. First of all is very important to mention, that it is not in our aim to produce technologically updated system or develop a new conductive material, which would replace the current options. On the market we can already found higher level of technological processing. We focus on new shape of already existed product, which would be more practical for some people´s activities and work. The new design can work as improvement of the product, which does not reduce the efficiency but rather increase the wearing comfort. Speaking especially about outdoor activities, which are based on sensitivity and finesse the fingers, there is still certain restriction for them. We would like to test the hypotheses, if it is possible to use artery system and blood circulation to transport heat from one area, where the heating system is applied, to another, so that the unprotected area will keep the acceptable temperature for life and health.

For the decisions on the presumption, we will use the provisional prototypes with different shape solution for practical testing (developed in cooperation with technological centre Leitat, Spain), theoretical knowledge, and finally the consultation of MUDr. Marie Pometlová from Third Faculty of Medicine of Charles University, Department of Normal, Pathological and Clinical physiology in Prague. She will provide us her initial and final opinion from the aspect of healthcare.

TECHNOLOGICAL CENTRE LEITAT

The following project is the result of cooperation with Technological centre Leitat in Terrassa, Spain. The principle of product is typical for combination of Textile Technologies Department and Smart Systems Department, both belong to this company. [1]

Leitat is a private non-profit association supported by the Catalan Government and by the Spanish Ministry of Science and Innovation. The main activity is collaborating with companies and other entities on research, development and innovative projects. [1]

I got the opportunity to spend my foreign placement at the department of Textile technologies working in Research and development area.

I. THEORETICAL PART OF THE THESES

1. PRINCIPLE AND HYPOTHESIS

1.1. Purpose of the product

There are a lot of people suffering from cold hands (or legs) during outdoor activities.

On world market there are a lot of companies producing heated gloves. But there is one important inconvenience we can find on those products. There are many activities, where is necessary to have a feeling in fingers, on even sensitivity and finesse the fingertips, and so they would restricts in these work or sport. For example: mountain climbers, rescuers, emergency services, hunters, shooters, sailors, fishermen or people working outdoor whole day in general.

Finally there are also people who suffer from "cold hands" as vascular disease, e.g. Raynaud´s syndrome.[2]
Raynaud´s phenomenon (RP) is functional vessel disorders caused by cold or emotion. This disorder is divided into two types. **Primary RP,** which cause is not known yet and **Secondary RP** called "Hand-Arm-Vibration Syndrome" - occupational disease caused by prolonged exposition of vibration while working with a manually operated pneumatic tools and vibration machines. [2],[3]
Symptoms of the disease are colour changes in segments of the fingers. First change is to white – cyanosis. Patient has no feeling in the fingers. After that it changes to red and the pain is coming. It comes usually in temperature between 13 – 15ºC and takes 20 – 30 minutes.[2],[3]

The solution may be not to expose the low temperatures or to wear warm gloves as a protection from cold.

The final product has the purpose to obtain warm hand, including fingers, and not to interfere in any work or human activity. The fingers should stay uncovered to be able to do accurate work depend on feeling in the fingertips.

1.2. Artery system of limb

Venous and artery system distributes blood and thereby also heat to all parts of body, as can be seen on the following picture. (Figure 1)

On this fact is based the hypothesis of this thesis: If it is possible to heat one part of upper limb to keep in warm the whole hand.

Heating system should be located on the ideal place of hand / arm and should heat the blood in artery to allow them to distribute this heat to terminal parts of hand (→palm →fingertips).

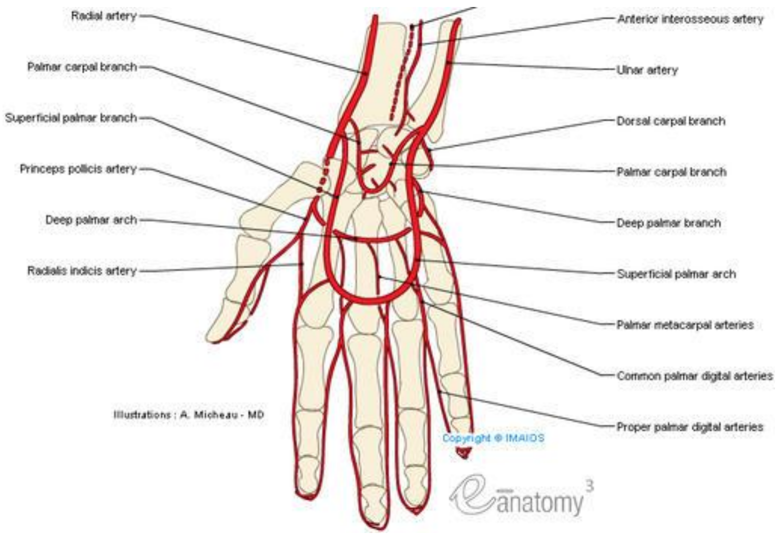


Figure 1: Artery system of upper limb [4]

As can be seen on the Figure 1, in wrist held two major arteries – *Arteria ulnaris and Arteria radialis.* Both begin in the elbow and connect with arterial arch in the palm. Arteries branches out and passed to all the fingers. [4]

Main idea is to test if it is possible to keep warm unprotected fingers heating wrist or/and palm. We assume, that, if is possible to increase the temperature of blood in the two major arteries, the passing blood will heat also the unheated fingers.

The final product of this project should be in shape of bracelet or fingerless gloves.

Final prototype will be a result of combination of textile and electronic components.

According to consultation with MUDr. Pometlová, we assume that this solution may be possible. We have to focus especially on safety of the product. Most likely, it would be useful mainly by helping people with the Raynaud´s syndrome, but it is possible that it will positively affect even healthy people.

2. STATE OF ART IN „THERMO“ PRODUCTS

There is wide range of applications using electronic components or thermoelectric effects to improve the product’s properties on market. One of the most popular groups of “smart products” is heated items of cloth. We can find heated jackets, vests, socks, scarves and, of course, gloves.

Following list is introducing the main companies that deal with the concept of heated gloves and try to acquaint the reader with their thermoelectric solutions and offer. Their products are currently available on the market.

Basically we can divide the solutions of heated items in two groups:
The first uses the metal resistance wires for the generating of heat and the second one came with a special solution of heated polymer fabric.

2.1. Solution: metal resistance wires

- Warmthru (UK)
    - Lithium Ion or Lithium Polymer batteries, 3-3.5hrs in continuous battery use
    - Hidden Velcro pockets for battery
    - Temperature range: 35-40ºC.
    - For hill walkers, yacht persons, outdoor sports enthusiasts, sport fans, hunters, photographers...
    - €136.40 [5]

- Gerbing´s (USA)
    - lithium batteries
    - zippered pockets on the cuff of the gloves
    - durable abrasion resistant nylon shell and a digital leather palm OR fleece gloves
    - gloves or mittens [6]

- Warmawear (UK)
    - Heating Elements run to tips of fingers
    - carbon-ceramic infrared heating element helping to promote efficient battery use and efficient distribution of heat [7]

We can mention much more companies, as Blazewear from USA [8], Alpenheat from Austria [9] and so on.

There is also one company focused on heated items and smart clothes situated in Plzeň, Czech Republic, called Applycon. [10]

2.2. Solution: heated polymer fabric

2.2.1. EXO2

This company developed the heated polymer called *FabRoc*®.
FabRoc® is a lightweight polymer that produces FIR (far infrared) heat energy when a low voltage is passed through it. This is what keeps the human warm.
Can be powered by either rechargeable batteries, a mains power adaptor, or from the accessory socket of a car or motorcycle.[11]

3. PHYSICAL CONCEPTS

3.1. Thermal conductivity

In physics, thermal conductivity “λ”, is the property of a material's ability to conduct heat. Thermal conductance is the quantity of heat that passes in unit time through a plate of particular area and thickness when its opposite faces differ in temperature by one kelvin. In metals, thermal conductivity approximately tracks electrical conductivity according to the Wiedemann-Franz law, as freely moving valence electrons transfer not only electric current but also heat energy. However, the general correlation between electrical and thermal conductance does not hold for other materials, for example in non-metals (see below the Table 1, page 18). [12]

3.2. Thermoelectric effects

There is couple of effect, which describes the transformation of electrical energy into heat energy. The effects are: Seebeck effect, Thomson effect, Peltier effect and Joule effect. These effects will be analyzed theoretically to decide, which one can be most suitable for our product. We decided to use one of the possibilities to distribute heat from the source of power through conductive materials and create the heating system. [13]

3.2.1. Thomson effect

This effect describes the process when a current flow through an unequally heated metal and there is an absorption or evolution of heat in the body of the metal. This effect is divided into positive Thomson effect and negative Thomson effect. In **positive Thomson effect** it is found that hot end is at high potential and cold end is at low potential. Heat is evolved when current is passed from hotter end to the colder end and heat is absorbed when current is passed from colder end to hotter end. In the elements which show **negative Thomson effect,** it is found that the hot end is at low potential and the cold end is at higher potential. Heat is evolved when current is passed from colder end to the hotter end and heat is absorbed when current flows from hotter end to colder end. [13]

3.2.2. Seebeck effect

This effect is based on temperature difference between two points in conductor. This difference results in a voltage difference between these two points and an electric potential (voltage) can drive an electric current in a closed circuit. That mean that temperature gradient gives rise to build electric field.

The electrons in a hot region are more energetic and therefore have greater velocity than those in a cold region. There is diffusion of electrons from the hot end to cold end. The situation prevails until the electric field developed between the positive ions in the hot region and the excess electrons in cold region prevents further motion from the hot to cold end. This effect works just for direct current.

Seebeck effect can be used in thermoelectric cooling or heating system.

For the application of Seebeck effect is used Peltier cell as well as for Peltier effect in common products. [15]

3.2.3. Peltier effect

An electrical current would produce heating or cooling at the junction of two dissimilar metals. The heat absorbed or created at the junction is proportional to the electrical current. The proportionality constant is known as the Peltier coefficient. Peltier cell is a thermoelectric device working on the Peltier phenomenon principle. It is mostly used for the active cooling since the cell allows us transfer of heat from the colder place the warmer one, which means in the opposite direction than the heat flows naturally. Peltier cells are commonly constructed of larger amount of semiconductor elements, which are connected in series from the electrical point of view and in parallel from the point of view of the heat transfer.[15]

3.2.4. Joule effect

Other way for heating system is using Joule effect. In many cases is Joule heat considered to be loss of electrical power. But it can be used also as a positive effect for generating heat. The wires are not perfect electrically conductive and are subjected to heat dissipation during passage of an electric current.
There have to be used network, which are directly connected to the battery.[11]

The amount of heat Q [J] generated over a certain period:

$$\mathbf{Q = P * t = U * I * t = R * I^2 * t \quad [J]} \tag{3.1}$$

P … electrical input power [W]
t … time [s]
U … electrical voltage [V]
I … electrical current [A]
R … electrical resistance [Ω]

The amount of Joule heat depends on the electrical input power P [W] of conductor:[14]

$$\mathbf{P = U * I = R * I^2 = U^2 / R \quad [W]} \tag{3.2}$$

After the theoretical review of the thermoelectric effects it was decided that for the final prototype will be used Peltier effect using Peltier cell or Joule effect, as the most suitable solutions for the product.

In case of Peltier solution the heat is generated in Peltier cell connected to the battery. The conductive fibres or yarns are only the mediator for transfer the heat to bigger area.
In contrast, Joule effect is realized by direct connection with wire system and battery. The heat is generated due to resistivity of wire as energy loss.[15]

3.3. Heat transfer

The principle of a protective glove with central electrical heating (GCH) depends in the use of a heater H with the surface areas A_{out} and A_{int} [m^2], thickness b[m] and mass m [kg].

Heat power loses Q* [W] from the outside oriented surface are

$$\mathbf{Q^*_{out} = \Delta t_{air} A_{out} / R_{tot}} \text{ [W]} \tag{3.3}$$

$$\mathbf{\Delta t_{air} = t_H - t_{air} [K]} \tag{3.4}$$

where the heater termperature t_h is higher then skin temperature t_{skin}

$$\mathbf{R_{tot} = R_{text} + R_{bl}} \tag{3.5}$$

Here, $$\mathbf{R_{text} = b / \lambda} \text{ [m}^2\text{K W}^{-1}] \tag{3.6}$$

b means the thickness of the fabrics creating the glove surface

λ (mostly 0,040-0,060) [$W.m^{-1}K^{-1}$], R_{bl} and other letters used for physical quantities are explained in List of abbreviations, page 7.

Thermal resistance of the boundary layer R_{bl} layer can be calculated as

$$\mathbf{R_{bl} = 1/ \alpha} \text{ [m}^2\text{K W}^{-1}] \tag{3.7}$$

For low air velocity v [m/s], the value of this heat transfer coefficient can be determined from the empirical equation $\boldsymbol{\alpha = 8{,}3\ c^{-1/2}}$.

Heat power loses Q* [W] from the heater surface touching the skin are

$$\mathbf{Q^*_{int} = \Delta t_{skin} A_{int} / R_{skin}} \text{ [W]} \tag{3.8}$$

presents the thermal resistance between the heater surface and the veins and arteries containing the circulating blood with the temperature t_{blood}. [14]

$$\mathbf{\Delta t_{skin} = t_H - t_{blood}} \tag{3.9}$$

Thanks to the heater, the circulating blood is heated to the temperature $\mathbf{t_{blood} > t_{skin}}$

The minimum heat power Q* for covering the stationary heat loses here consists of

$$\mathbf{Q^* = Q^*_{out} + Q^*_{int}} \tag{3.10}$$

Heating dynamics of the heater with heating imput P[W] is approximately given by the simplified equation (provided that the initial temperature of the heater after few seconds becomes t_{skin}).

$$\mathbf{t_H(\tau) = t_{skin} + [(P - 0{,}5Q^*)\tau/(m \, .c_p)]} \tag{3.11}$$

Here, the c_p presents the specific heat [J/kg/K] of the heater material at constant pressure. After certain time τ, the temperature of the heater will reach its maximum (practically) constant temperature t_H (max), which also brings the maximum blood temperature in the palm and consequently in the fingers. [14]

The thermal model of the human body examined Dr. Jones from University of Kansas and other researchers. But our calculation would be just estimates of real states of body. Therefore we will follow with practical testing of the prototypes on variety of humans in several conditions without estimates concrete values.

4. TASKS TO SOLVE

During the way to the optimal prototype for the testing, couple of tasks has to be decided. The following points are the main we have to focus on. According to the state of art described in the chapter 3, our prototype will follow the easiest and cheapest way from available materials.

4.1. Heat distribution

The purpose is to produce merchandise with suitable heating features for simulation. There are two types of distribution – see *Thermoelectric effects* chapter 3.2.

The most appropriate system will be found through experiments in practical part of the thesis. We have to choose between Peltier cell using Peltier effect and direct heating using resistive wires (Joule heat).

4.2. Heat source

This task is discussed theoretically up to the previous chapters again. There are couple of possibilities from typical resistive wires to special materials developed recently. As we aim to come with temporal prototype to test our hypothesis, the classical solution in the form of resistive wires is sufficient. To reach FabRoc or Thermoknit fabric is too expensive and not necessary for our target.

4.3. Supporting fabric

The final efficiency can be affected and improved by underlying fabric. We can test these possibilities by changing the substrate material.

We will use the common textile fabrics used for winter clothes or thermoelectric products available in the Technological centre.

5. TECHNICAL EQUIPMENT

Following devices will be used for observation and measurement of temperature changes in a particular place. The certain meaning and application of all the devices are described below.

5.1. Generator of electrical voltage

Connection with generator can help us to find out current consumption at a certain voltage which is needed to determine the conductor resistance. Generally it can be used for rapid detection, whether the current passes through the conductor or not.

5.2. Thermocamera

The thermal camera operates on the principle of non-contact temperature measurement. All objects whose temperature is greater than absolute zero emit electromagnetic radiation.

The camera allows observing changing in temperature of the sample and taking photos or record the video. The temperature differences are noticeable by colour distinction according to colour range. To the final photo-documentation can be added marks to indicate an exact temperature at a certain point, or a minimum and maximum temperature of the whole sample.

The very important aspect is to determine the right emissivity of scanned material.

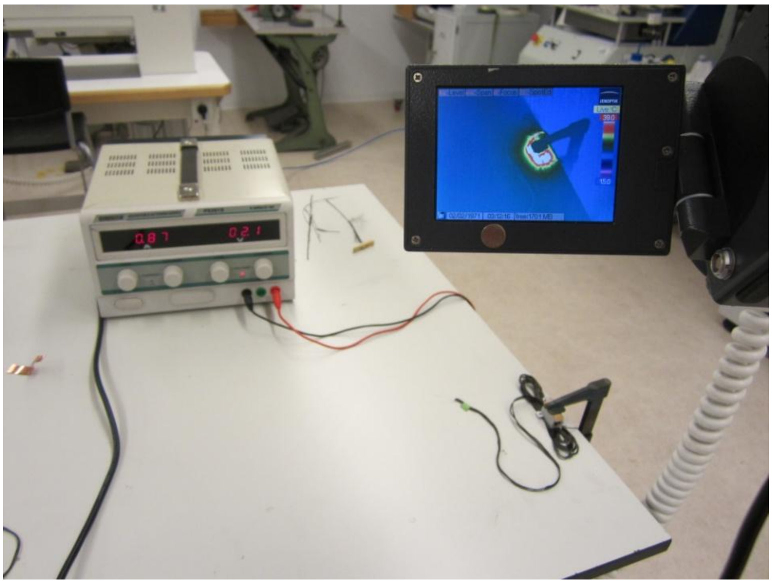


Figure 2: Generator and thermocamera

5.3. Temperature sensor

For determination of skin temperature will be used also temperature cable sensor and measuring device ALMEMO 2590 by AHLBORN Company. This is the contact measurement. Scanning and reading values is very accurate. Temperature sensor is in the form thin coated Ni-CrNi thermocouple (tube diameter 0, 5 [mm]) and can scan the temperature in wide range of values. This device allows also recording all data in its memory for later use.

Figure 3: Temperature senzor ALMEMO

6. CONDUCTIVE FIBERS

This is the second important part of creating the final prototype of this project. The heated system will be prepared as a network of conductive material. From the first hypothesis came the idea of using carbon yarns or fabrics for this system.

The meaning of conductive fibres, in general, is mostly about electrical conductivity, but also thermal conductivity is a phenomenon based on similar properties of material. It depends on amount of free electrons in chemical structure of the material. [17]
There are a lot of different types of conductive fibres. We can divide them into two main groups: **Metal fibres/yarns and yarns consisting of conductive polymers**.
Metal fibres are well known for a long time. These include mainly copper, silver, gold, zinc or stainless steel. Recently is more and more growing use of carbon fibres. They can reach high quality in different properties depending on the manufacturing process.
Huge group of conductive fibres are multicomponent, including textile fibres with metal coating, yarns with metal core or metal fibres intertwined with usual textile fibre like PAD, WO, CO etc. [17]

There is wide range of utilization in textile applications:

- Electromagnetic protection
  - medical textiles (e.g. in radiologists)
- Antistatic protection
  - protection in explosive environments against sparks
- Electrical conductivity (smart textiles)
- Technical textiles (resistant gloves …)
- Protection antifungal and antibacterial
- THERMAL CONDUCTIVITY → THERMOREGULATION

The first task is to determine the most suitable textile yarns with the best property of thermal conductivity for the following application.

II. EXPERIMENTAL PART OF THE THESES

7. HEATING SYSTEM

7.1. Heating network – material

The next step in this work will be to find conductive material, which can be used for our application. Following tab shows five materials with the best conductivity

TIBTECH	Electrical conductivity (10.E6 Siemens/m)	Electrical resistivity (10.E-8 Ohm.m)	Thermal Conductivity ($W.m^{-1}K^{-1}$)	Thermal expansion coef. 10E-6(k-1) from 0 to 100°C	Density (g/cm3)	Melting point or degradation (°C)
Silver	62,1	1,6	420	19,1	10,5	961
Copper	58,5	1,7	401	17	8,9	1083
Gold	44,2	2,3	317	14,1	19,4	1064
Aluminium	36,9	2,7	237	23,5	2,7	660
Molybden	18,7	5,34	138	4,8	10,2	2623

Table 1: The best conductive materials [19]

In the following chapters will be described four types of available conductive materials and evaluated their featured and suitability for our purpose.

7.1.1. Carbon yarns from HAVEL Composites Company

According to available information, as the most appropriate material were chosen carbon fibers. This material can reach conductivity up to 1000 W/m K. Moreover have excellent features as high tenacity, strength or stiffness.
The samples were provided by *Havel-composites Company* (CR) but the producer is *TohoTenax Europe GmbH* (Germany). **There is the product sheet available (you can see it in the addition 1 of this thesis) but the information about thermal conductivity is missing.** Therefore were made the samples of them for using Peltier effect and do the measurement of conductivity. [20]

The *Havel Composites Company* provides following samples of carbon yarns [18]

CARBON YARNS	
HTS	800tex
HTS	1600tex
STS	1600tex
UTS	800tex
IMS	830tex
UMS	800tex
HTA	800tex

Table 2: Carbon samples from HAVEL Composites Company [18]

There are yarns differing in stiffness, fineness, sizing and finishing.

These samples were tested by resistant cell fixed with the sample and connected with generator of voltage. Results are scanning by thermal imagining camera (Figures 4 & 6). The purpose is to find out, how the heat is from the resistant cell distributed through the sample and what temperature it can obtain for different samples. For the illustrations were chosen sample of UMS 800 tex.

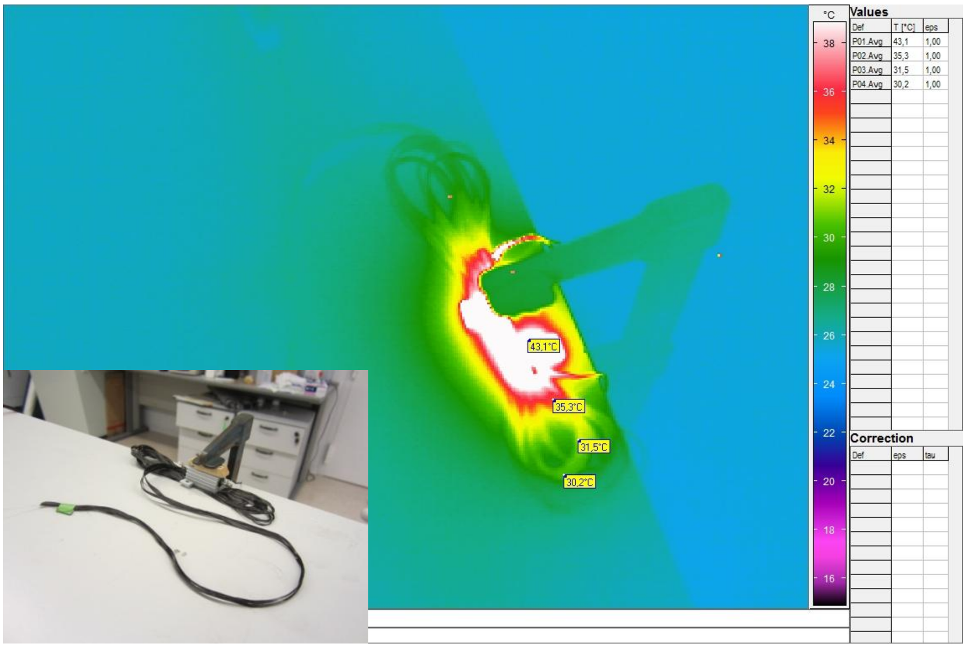


Figure 4: Testing of conductivity of the carbon sample by thermocamera

The final product should have the shape of network on palm-part of hand covering this area as good as possible. It is necessary for equal distribution of heat. We will use the yarn UMS 800 tex for the network and scan it again. As the first idea for network was created the shape you can see on the Figure 5.

There are two ways how to make the network connecting with the underlying fabric: sewing with machine or hand sewing. For the carbon yarn will be better to use hand sewing, because this yarn is untwisted and badly held in one line. Sewing with machine can be difficult and useless in this case.

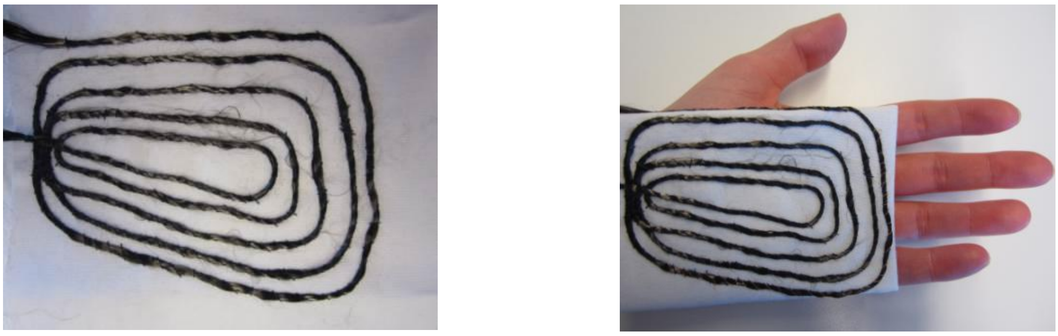


Figure 5: Conductive network for palm made from carbon fibres

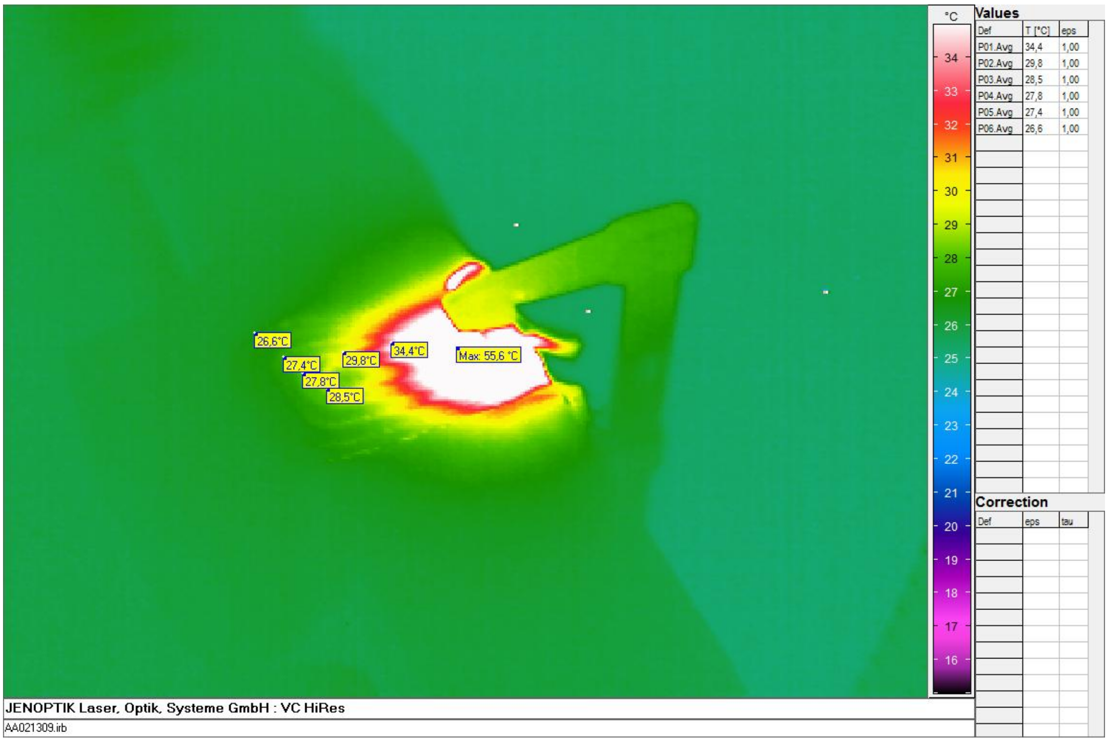


Figure 6: The conductive carbon network scanned by thermocamera

According to the pictures from thermal imagining camera can be said, that thermal conductivity of all samples is very low.

There are a lot of different types of carbon fibres with different properties available on the market. The thermal conductivity range from 10 to 1100 [$W.m^{-1}K^{-1}$], depends on the precursor (PAN, pitch) of the fibres and on the finishing process.

E.g. **Mitsubishi Plastics** provides carbon fibres with thermal conductivity up to **800 [$W.m^{-1}K^{-1}$]. (Pitch based, Continuous Fibre 2K, type K13D2U**) or **CYTEC.COM** and their fibre **K1100 (Pitch based)** with conductivity more than **1000 [$W.m^{-1}K^{-1}$].** [21]

All the samples provided by Havel composites Company are PAN based. In general, PAN based carbon fibres has much lower thermal conductivity than pitch based carbon fibers.

The final decision is not to use these materials because their properties are not suitable for this application. Solution can be to win some of the pitch based materials, but it is beyond the possibilities of our project.

The next step in this project will be to find another conductive material, which can be used for our application. Following tab shows five materials with the best conductivity

7.1.2. Silver coated thread – provide by LEITAT

One of the best conductors, in general, is silver. The thermal conductivity reaches up to 420 [$W.m^{-1}K^{-1}$]. [17]

This thread was bought from *Less EMF Inc Company* as one of the highly conductive materials in their product sheet. According to the product sheet, this thread is polyamide yarn (PA 6.6 - ¨nylon¨) with silver coating, what means good strength as well as high thermal conductivity. They claim the resistance up to 1000 Ω/10cm.

Due to measurement by generator of voltage was determined, that the real state of the sample´s conductivity is just 0, 4 Ω/10cm. In fact, this is only a nylon yarn with a very small amount of silver coating on few filaments. The amount of silver is insignificant and the thread has very low conductivity.

Can be said, this is a type of deceptive advertising. The sample won´t be used neither for the application nor for the testing.

Figure 7: "Silver coated" thread

7.1.3. Copper yarn twisted with wool – provide by LEITAT

Copper is well known as high conductive material. Thermal conductive properties can reach to more than 400 [$W.m^{-1}K^{-1}$]. The disadvantage is fragility which strongly limits the use. [17]

This fact followed to the idea of new thread, which can keep the positive features of copper but improve the strength and durability of the material. The new product is based on the wool yarn twisted with copper fibre and was created by Technological centre of Leitat. This is still not available on market but there is the option to use it in this project due to cooperation with Leitat.

Figure 8: Copper yarn twisted with wool

This yarn will be tested in the same way as the carbon yarn. Will be prepared the network of this yarn in the same shape as the carbon yarn for testing the thermal conductivity and compare the results. We will use the hand sewing again First we will measure the yarn by resistant cell fixed with the sample and connected with generator of voltage. The results are watching by thermal imagining camera.

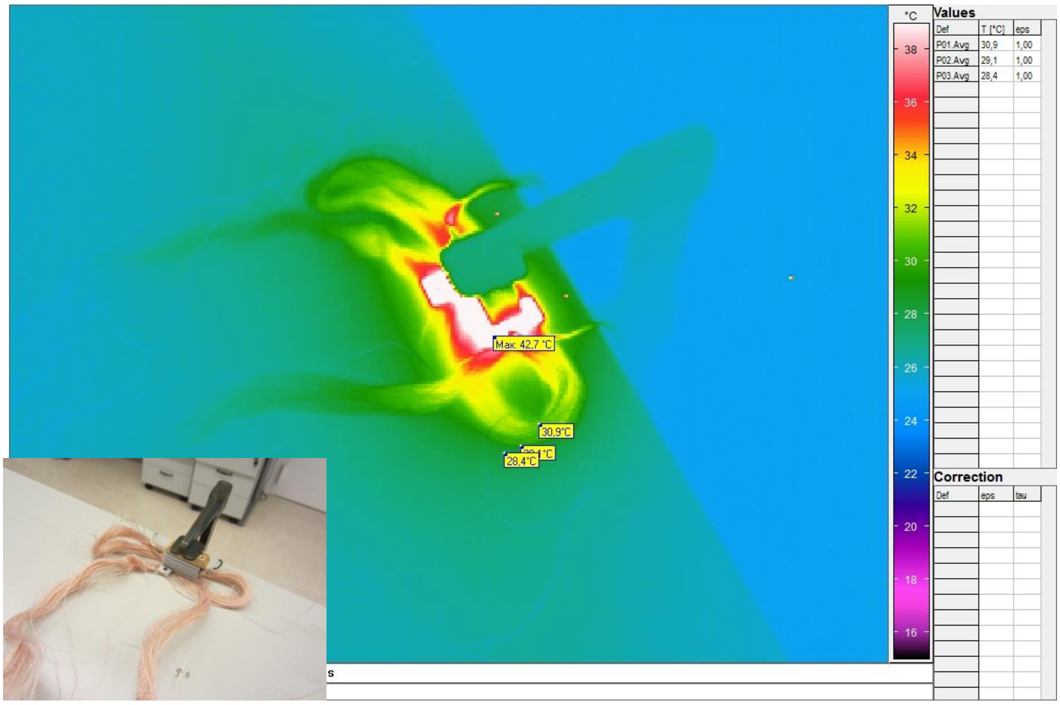


Figure 9: Copper yarn twisted with wool scanned by thermocamera

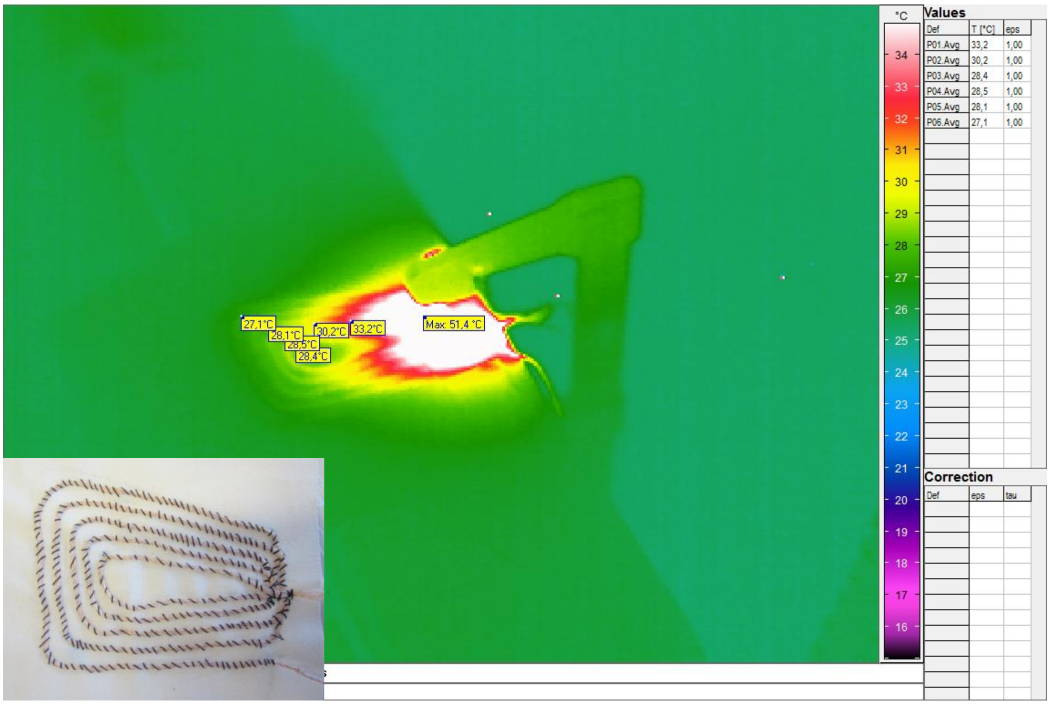


Figure 10: Network for palm from Copper/wool yarn scanned by thermocamera

In comparison to carbon yarn is the conductivity of this sample higher, but still insufficient. The wool part is improving the strength of the yarn, but on the other hand, works as insulator. This solution of copper´s fragility brings positive but also negative results.

7.1.4. Copper yarn

There is another sample made just from copper fibres for comparison with the previous one.

- **One fibre**

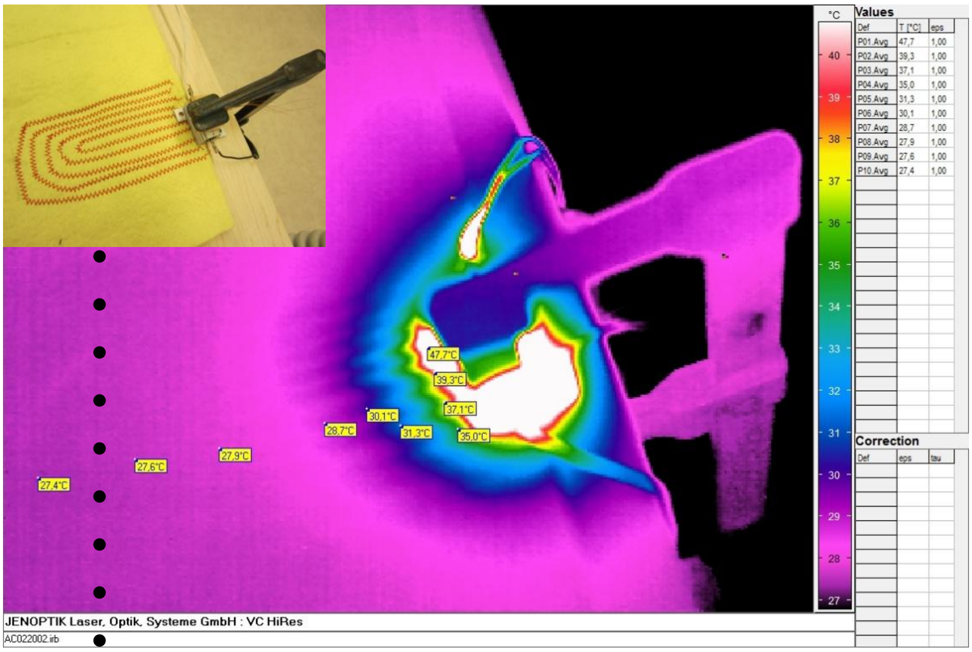


Figure 11: Network for palm from copper scanned by thermocamera

- **Eight fibres**

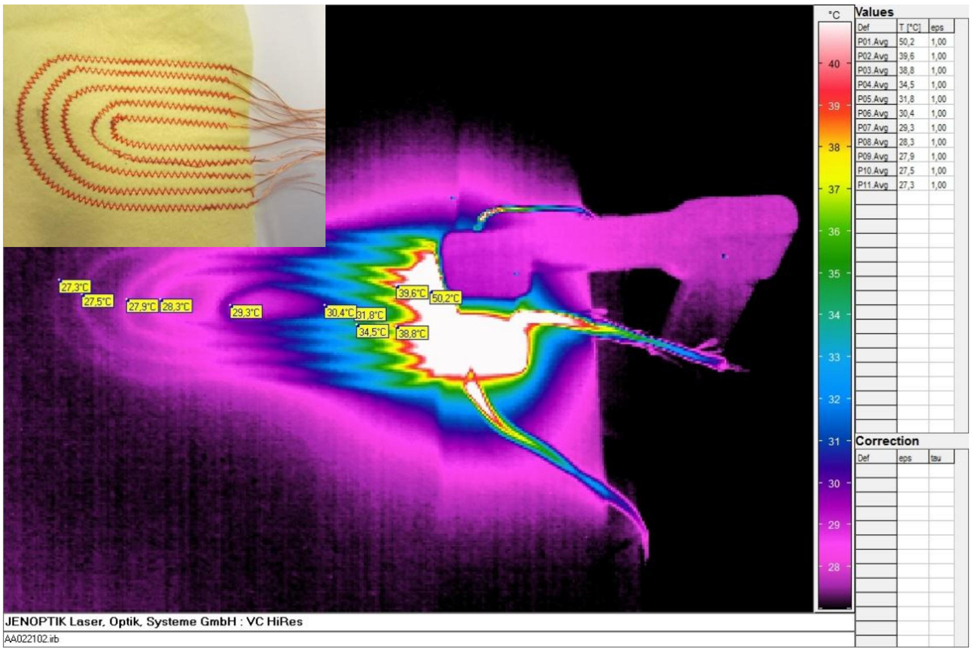


Figure 12: Network for palm from copper scanned by thermocamera

From the Figures 11 and 12 is clear, that 1 copper fibre has not sufficient potential for heat conduction. If we use more fibres, the amount of transported heat will be obviously higher. The advantage compared to the previous sample is that we do not have to removing the wool before connection with source of power. But we have to be careful due to the fragility of the fibre.

In the appendices you can find the detailed photos of twisted copper used in this sample.

Following table summarize the results from all measurements and tests made in previous parts of the project.

SAMPLE	TEXTILE MATERIAL	PROPERTIES			
		conductivity	strength	feasibility	general suitability
1	carbon PAN based	✗	✓	✗	✗
2	silver coated thread	✗	✓	✓	✗
3	copper twisted with wool	✓	✓	✗	✓
4	copper	✓	✗	✓	✓

Table 3: Features of materials

From the above mentioned options, the most important property for this application is thermal conductivity, **which eliminates the use of samples 1 and 2. The table shows the only suitable solutions are either wool yarn twisted with copper fiber or just copper fibers.**

From the previous testing follows, that using Peltier effect and thermal conductive fibres is not sufficient solution enough. **Therefore we will continue using Joule effect and the feature of electrical resistance of wires, trying to deal with some inconveniences of the materials 3 and 4.**

In the sample 3, copper twisted with wool, the woolen part has to be removed at the ends of network which will be connected with source of power and also the coating of resin on the copper fibres should be dispose of with solder. It is quite difficult and takes longer time. But still seems to be the best material of the samples. The sample 4 - copper fibre – has very good properties and the application is easy and quick, but it is very fragile.

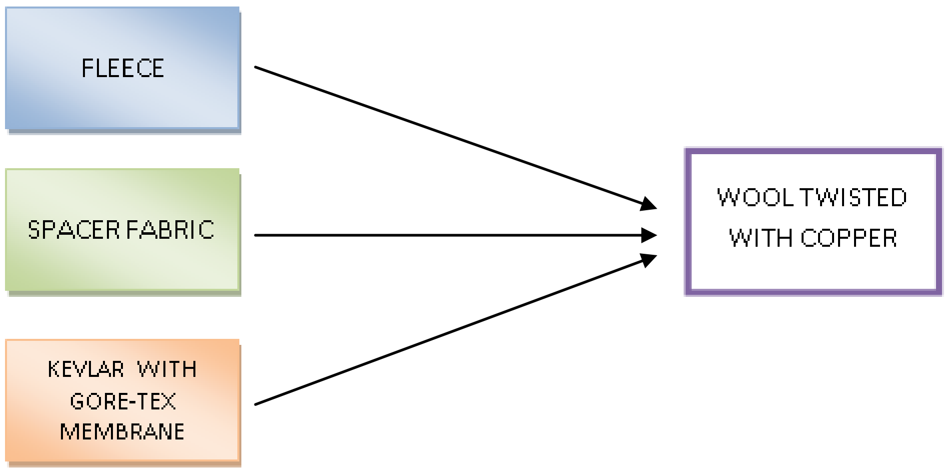
7.2. Heating network – Shape

During the prototyping is used a lot of different shapes of network. Some due to cover the wrist part of the hand, some also for palm or even back of the hand. Because of the function, the electrical circuit must not be interrupted, so the whole length of wire is in one long line.

7.3. Supporting fabric

The final efficiency can be affected and improved by underlying fabric. We can tested this possibilities by using the same yarn (copper twisted with wool) network and changing the substrate material.

The size and shape of the network should be maintained on each sample.
We will use the common textile fabrics used for winter clothes or thermoelectric products.



7.3.1. Fleece

Fleece is a knitting fabric with hairy surface. The main advantages are softness, lightweight and warmth. The clothing made from fleece fabric is very comfortable especially in cold conditions.

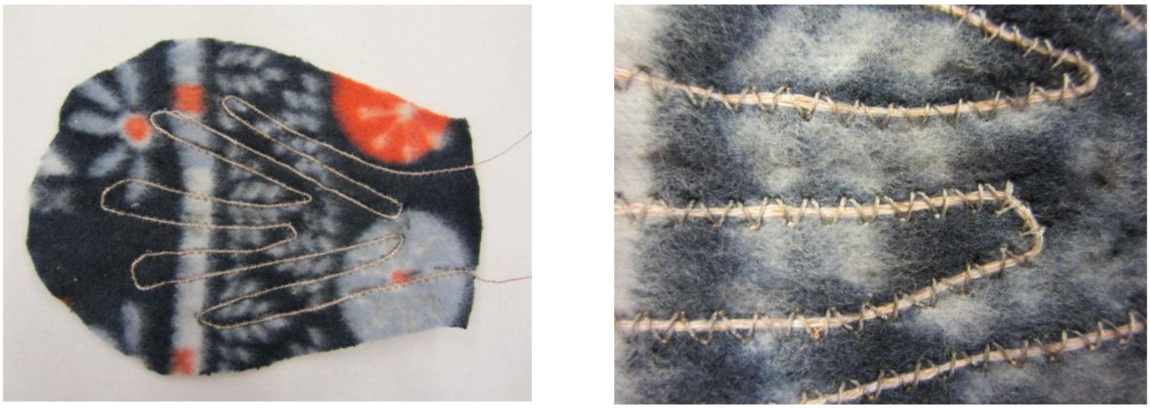


Figure 13: Sample of conductive network on fleece fabric

7.3.2. Spacer fabric

Spacer fabrics are much like a sandwich and feature two complementary slabs of fabric with third layer tucked between. The inner layer can take variety of shapes which gives the three-layer fabrics wide range of potential applications

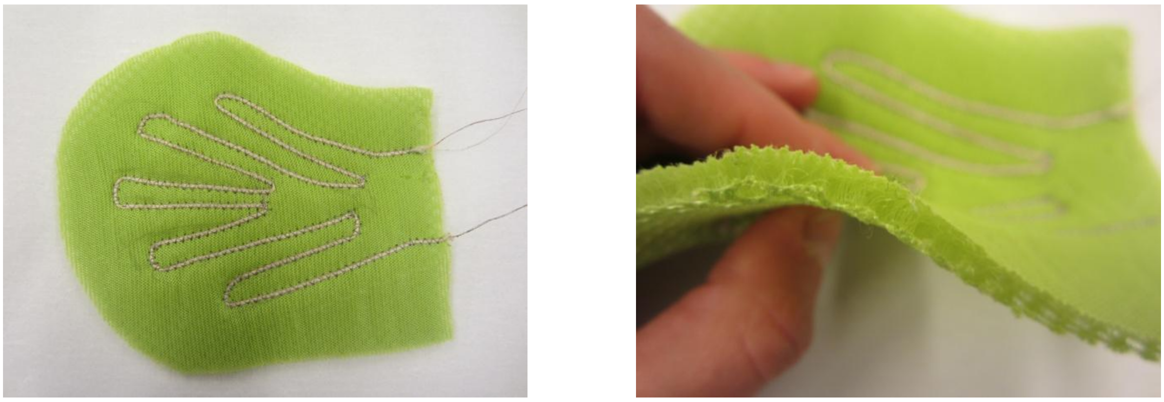


Figure 14: Sample of conductive network on spacer fabric

7.3.3. Kevlar with Gore tex membrane

Kevlar is highly resistant cloth from aramid fibers, but still is very thin and pleasant for touch. The Goretex membrane makes this fabric also wind- and waterproof.

This network was connected by the generator of voltage and scanned by Thermal camera. The results show the Figures 17 and 18.
The wool has to be removed from all threads before the joining and cleared by solder.

Figure 15: Sample of conductive network on kevlar fabric

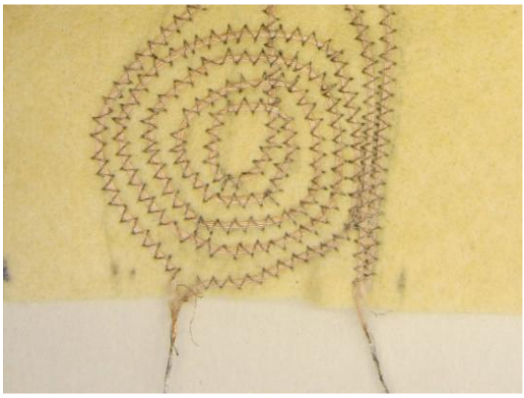


Figure 16: The endings of network

7.4. Heating network - Length

The previous sample was made by 2 lines of yarn with different length. First was made the longer – inner line finishing with the spiral. The spiral makes the line of thread very long.

After that was made the shorter – outer line bypassing original shape from the outside. The ends of both lines were joined together because we want to achieve just two junctions for making close circuit and using Joule effect.
We have demonstrated that the amount of joule heat depends on the length of wire.

Figure 17: The longer wire in network scanned by thermocamera

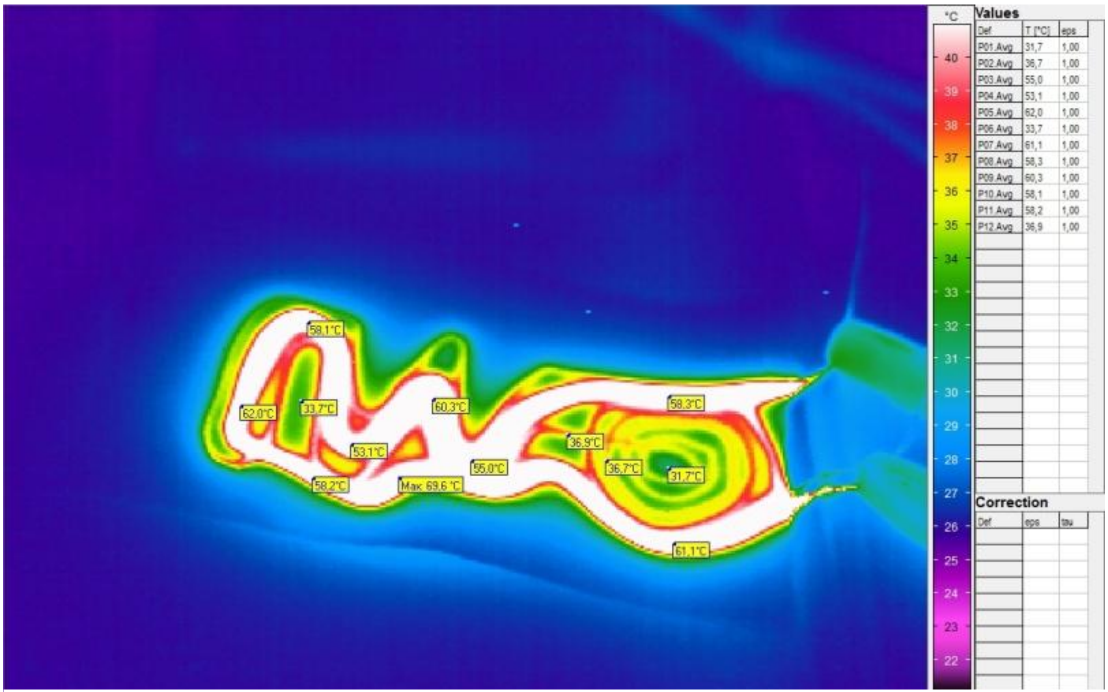


Figure 18: The shorter wire in network scanned by thermocamera

There are prepared 7 samples of copper wires of various lengths. It runs from 140cm to 80cm. Each sample Is 10cm-shorter than the previous one.

The following test should give us the necessary information about the certain temperature we can obtain with certain length.

According to Figures 17 and 18, the joule heat depends on the length of conductor - conductive yarn. We have to consider the length of yarn as well as the shape for constructing the most appropriate sample

JOUL HEAT - DEPENDENCE ON THE LENGTH OF CONDUCTOR (COPPER + WOOL YARN)				
sample	length [m]	voltage [V]	current [A]	temperature [ºC]
1	1,4	3,6	1,1	34,8
2	1,3	3,6	1,2	36,7
3	1,2	3,6	1,2	37,7
4	1,1	3,6	1,3	40,5
5	1,0	3,6	1,4	46,1
6	0,9	3,6	1,5	48,0
7	0,8	3,6	1,6	57,0

Table 4: Dependence of joule heat on the length of conductor

We try to find a suitable curve for the specified points describing their tendency using Least Squares method.

Hyperbole: **T = a + b / (l + c)** (7.1)

T = temperature

l = length

Parameters a, b and c are selected to minimize this.

Parametres:

a	21,10
b	13,38
c	-0,425

Parameters' estimation by Least Squares method. [22]

sample	length [m]	temperature [°C]	Fitted temperature [°C]	Residuum [°C]
1	1,4	34,8	34,81	-0,01
2	1,3	36,7	36,38	0,32
3	1,2	37,7	38,35	-0,65
4	1,1	40,5	40,91	-0,41
5	1,0	46,1	44,35	1,75
6	0,9	48,0	49,25	-1,25
7	0,8	57,0	56,74	0,26

Table 5: Length and temperature from Figure 4 extended by Fitted temperature and Residuals

Auxiliery table for the plot:

1,47	33,90
1,4	34,81
1,3	36,38
1,2	38,35
1,1	40,91
1,0	44,35
0,9	49,25
0,8	56,74
0,75	62,22

Sum of Squared Residuals **5,36**

The correlation = -0,956

R-Squared (coefficient of determination) = 98,54%

The correlation of temperature and length is slightly lower due to the fact that their dependence is not linear but convex. [22]

There is almost perfect smooth monotone dependence of the temperature on the length, as you can see on the following Figure 19.

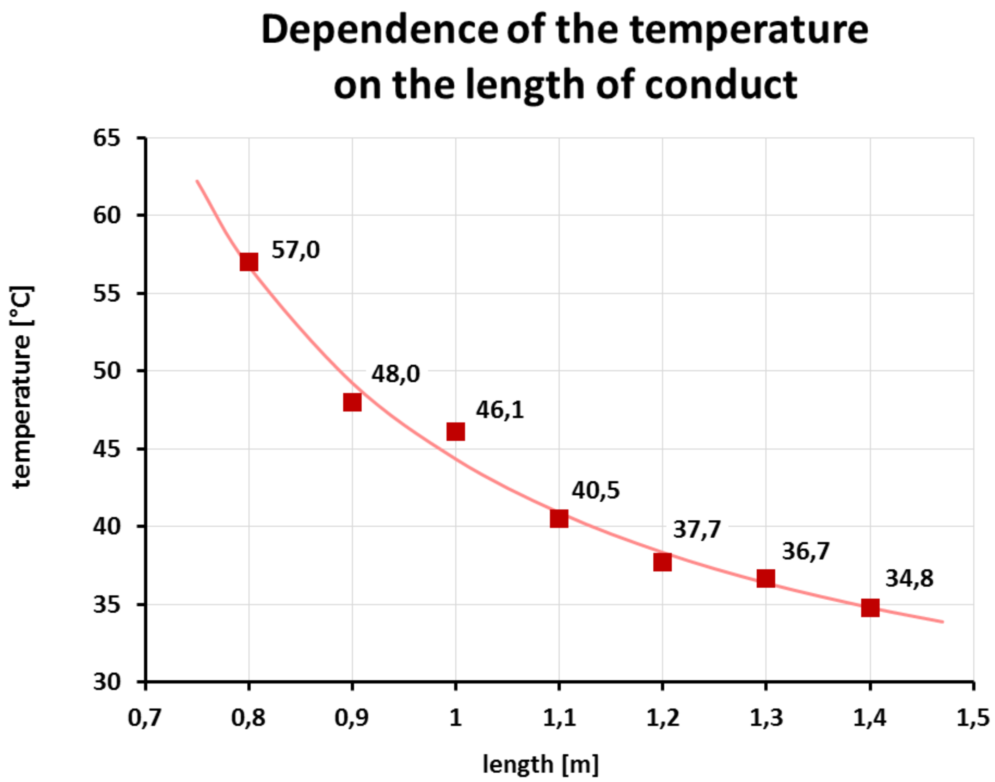


Figure 19: Dependence of joule heat on the length of conductor

S
kin temperature under normal conditions is approximately 32ºC. Very high temperature can caused injuries on the skin. Some of a medical articles talking about the temperature over 50°C, but the value cannot be accurately determine.

We will probably use interlayer for protecting the skin and also protecting textile network. Anyway we have to avoid any possibility of danger.

For the prototype was chosen the length of 100cm. We would be able to achieve sufficiently high but not dangerous temperature.

This consideration leads to sample consists of network for wrist (or wrist and palm) made from the resistive wire in the length of 100cm.

7.5. Source of power

As the source of power will be used the Lithium-polymer battery 3,7V 2400mA. See the Figure 20.

For the connection we have to make the junction, which will allow us to connect and disconnect the battery from the wire network easily and fast in case we need to switch the system on or off. The same is needed for the charger. The battery will be hidden in a small pocket so that can be easily removed to recharge if necessary.

Will be used solder for all the adjustments.

Figure 20: Lithium battery Fullwat

8. BATTERY LIFETIME

The final prototype has to include source of power – in this case the Lithium-polymer battery. For finding the battery lifetime is used the device Oscilloscope, which captures the process and time that supplies the closed circuit. There is the battery 3,7V 2400mA used for the measurement.

Regards the results from oscilloscope, this battery is able to supply our certain heating system of the gloves for the duration of 2 hours and 20 minutes at continuous operation.

The print screens from video record of battery lifetime are attached to the end of this thesis in part of appendices (APPENDIX 3). Each picture is taken 20 minutes after the previous one.

9. DESIGN OF THE PROTOTYPES

9.1. Prototype 0 – Pre-prototype

The shape in all previous samples used to be just separated sheet for palm and later also for wrist. The new design is in the shape of bandage around wrist and palm, so the heating system can affect the hand temperature from all directions

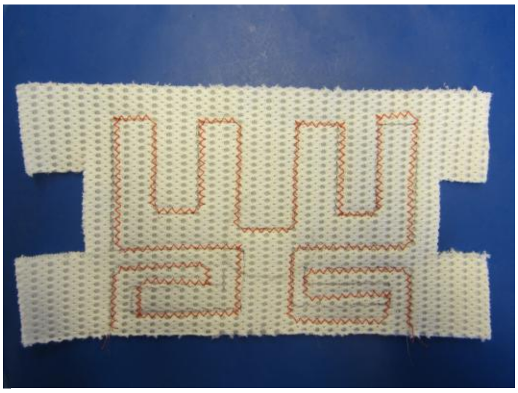
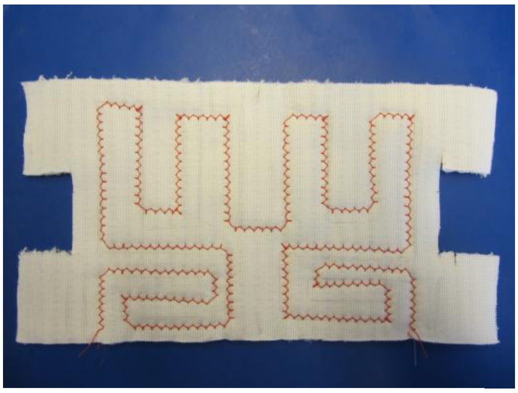



Figure 21:: Developed shape of bandage


Figure 23: Bandage from the palm and from back side of hand

Figure 22: Conductive network in detail

For this “bandage” was used the copper twisted yarn in the length of 100cm and the spacer fabric as the underlying material. To facilitate donning on the hand will be used Velcro for fixing on the thumb side of the hand.

For this sample was used spacer fabric, because it has very good thermal properties and moreover it is strong and flexible material that keeps his shape very well.

This is pre-prototype as first attempt of self-supporting heating. For real prototype of product we will not use the spacer fabric, but rather material more resistant to ambient conditions.

9.2. Prototype I

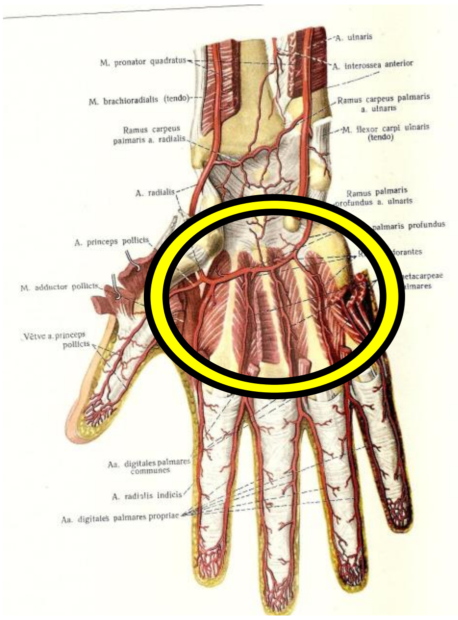


Figure 24: The area of hand affected by heat

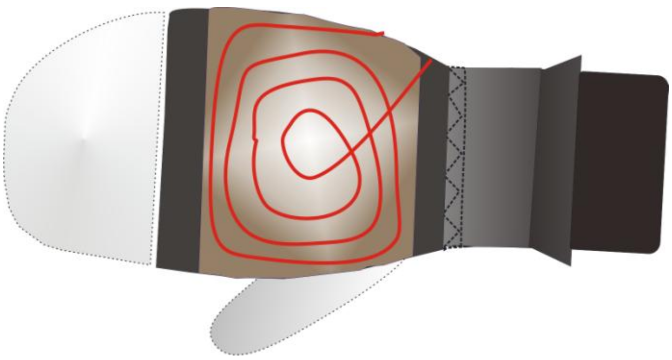


Figure 25: Technical sketch of back of the glove made in Corel draw

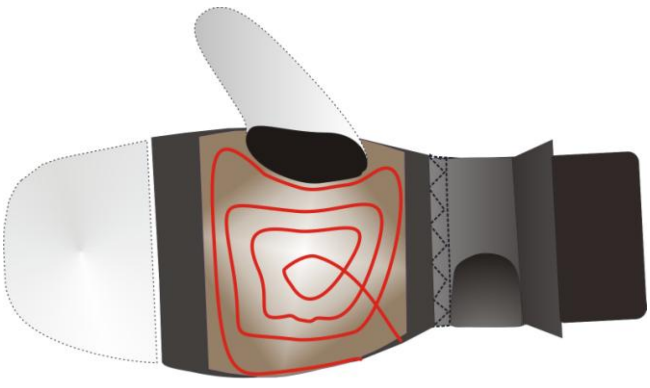


Figure 26: Technical sketch of palm side of the glove made in Corel draw

The prototype is based on usual mittens for sport.

- ***Outer fabric:*** ***100% PA***
- ***Palm fabric:*** ***60% PU / 40% PE***
- ***Lining fabric:*** ***100% PE***
- ***Padding:*** ***100% PE***
- ***Heating network:*** ***copper yarn***

Figure 27: The original mittens before modifying

The convenience of these mittens is that the lining fabric can be easily detached and the whole system opened to work with the layers separately. On the lining fleece fabric is applied padding for stronger warm feel.

Figure 28: Removing of the inner woolen layer from lining

The padding can be replaced with our layer with integrated heating system. Thus will be the heating system protected from both sides and to addition hand will be protected against potential high temperatures or even burns. The inner fleece layer separating the heating system and the hand is thin enough to transfer the generated heat through towards the hand allowing it warm up.

Figure 29: Heated fleece interlayer with the network of twisted copper yarn

In contrast to the previous sample – pre-prototype- the heating system is applied on fleece fabric instead of spacer fabric. The convenience is less volume of the textile material, which can be easily hidden inside the gloves but still does not interfere with the movement of the hand. In this case the heating system is permanently attached to the mittens so it is not necessary to hold the shape.

Figure 30: The heated interlayer integrated into the glove

Our purpose is to allow free moving of fingers; therefore we divided the palm-side and the thumb pocket of mittens into two parts. At that place can be the upper part of mittens opened or closed again using Velcro stripe. There is the snap metal fastener which can easily and fast join the two parts together at the back of hand to keep the mittens opened.

Figure 31: Closed glove

Figure 32: Opened glove

There is small pocket inside to hide the battery at the outer part of wrist. The pocket is closable with snap fastener but in case of lack of space there is also stripe around wrist to hide and close this gap.

Figure 33: Closed wrist pocket and opened wrist pocket with battery

The inconvenience of this prototype is that the heating layer cannot be removed from the glove. In case of washing we can take off just the battery but the wire system will stay inside the glove.

Figure 34: Opened glove dressed up on hand from palm and back side

9.3. Prototype II

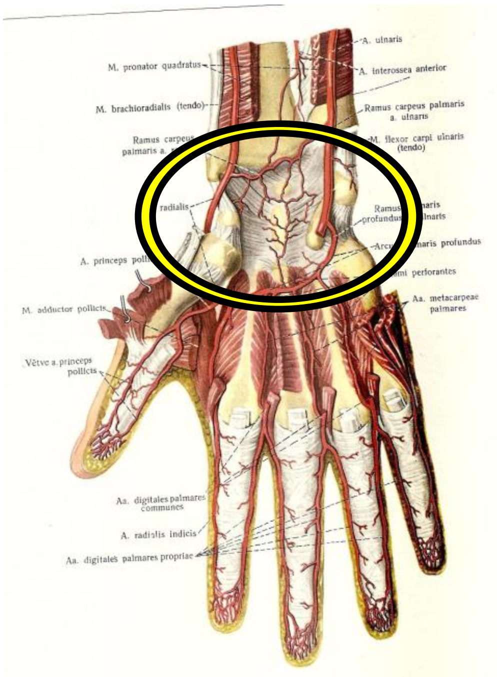


Figure 35: The area of hand affected by heat

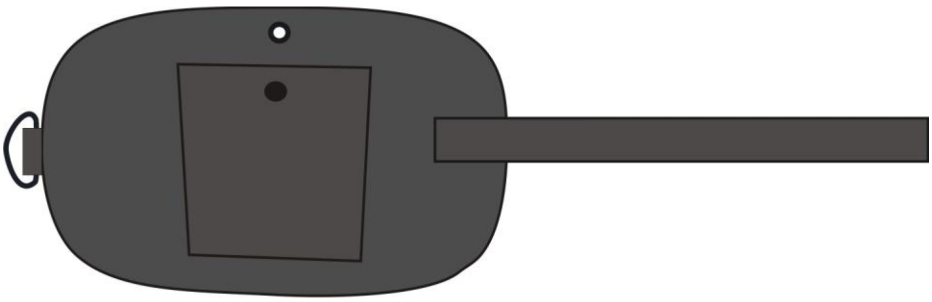


Figure 36: Technical sketch of bracelet front side made in Corel draw

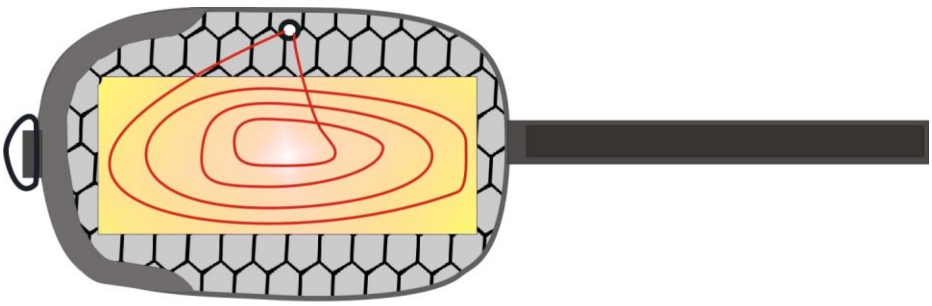


Figure 37: Technical sketch of bracelet reverse side made in Corel draw

- ***Outer fabric:*** ***neoprene***
- ***Lining fabric:*** ***CORDURA® (PA 6.6)***
- ***Inner fabric:*** ***netting fabric (PE)***
- ***Heating network:*** ***copper yarn on rip stop polyamide closed in hot melt PP***

This type of prototype is in shape of bracelet covering mostly the inner part of wrist.

As the supporting fabric was used neoprene. Neoprene exhibits good chemical stability, and maintains flexibility over a wide temperature range. This prototype is designed more like a technical product than textile accessories.

Figure 38: Opened and closed bracelet support part

At the beginning was the copper network sewed on rip stop polyamide fabric and covered with another the same layer. After that, was used the thermo foil for closing the whole system. The convenience in compare to Prototype I is that the heating network is closed inside waterproof foil, therefore is the system protected from different climatic conditions and to addition can be easily disconnected from the battery and removed in case of necessary of washing.

Figure 39: Conductive network closed in foil

There is netting lining fabric used at the inner side of the bracelet. It is a loosely woven fabric with a large number of closely and evenly-spaced holes, making it lightweight and breathable. Thanks to the softness and lightweight is usually used as lining fabric in all sportswear and equipment. In general netting fabrics are made from synthetic materials, especially polyester or polyamide.

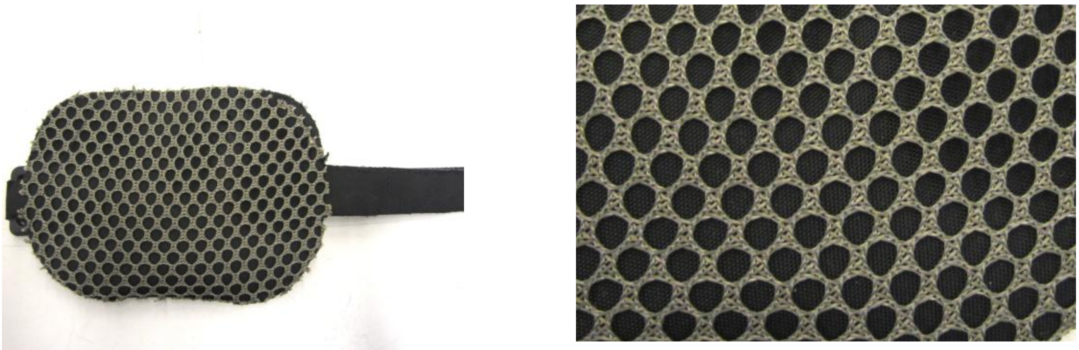


Figure 40: Netting lining fabric as pocket in inner side of bracelet

In our case we are using the netting fabric as a pocket for heating system. The advantages of the material are the evenly-spaced holes which allow unlimited passage of heat through the material. Can be said that the skin is in close contact with the heating system for warming but still is protected by the foil and netting fabric. Another convenience is the strength of the fabric which makes the pocket able to hold the whole system. This layer can be opened on one side due to rounded Velcro strip around the shape of the bracelet edge.

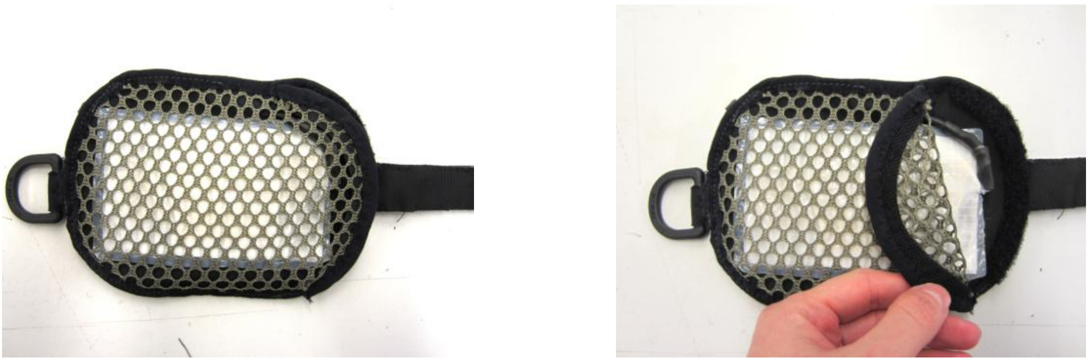


Figure 41: Thermo foil with conductive network closed in the bracelet

There is a pocket made from neoprene on the surface of the bracelet for saving and holding the battery. This pocket is closable by two metal snap fasteners and the user can manage to close and open the pocket just with one hand.

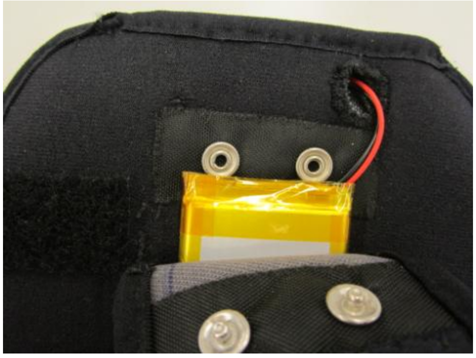



Figure 42: Opened and closed battery pocket on the front side of bracelet

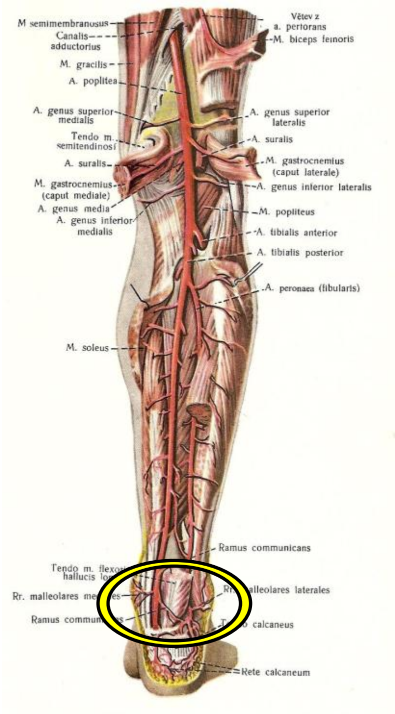
The connection between battery and heating sheet is realized by standard male and female jack and is situated in the space between two fabric layers of bracelet. The wires from battery and heating sheet are going through gap in the fabric and meet in the middle - inside the bracelet. This place is suitable because the connection is protected and does not affect the wearing comfort. The fastening system is made from stripe of Velcro which allows reduce or increase the perimeter of bracelet depending on the thickness of the wrist.

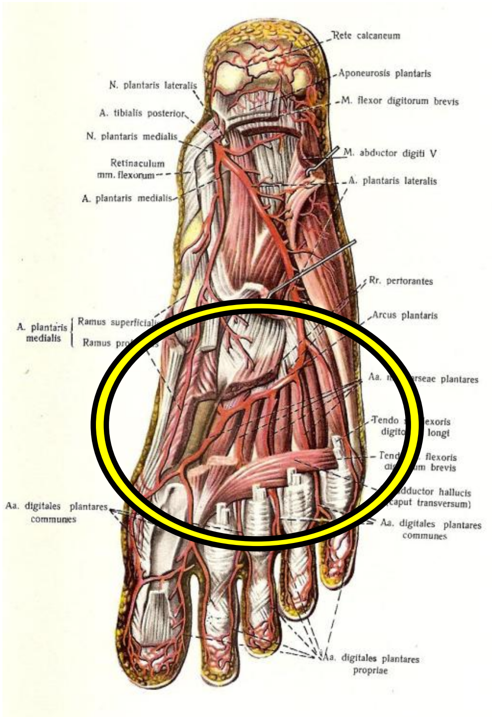

Figure 43: The final appearance of bracelet in fixed position

Figure 44: The final bracelet dressed up on wrist

This type of prototype would be also possible to use for lower limb. There should be done just small changes in fastening system.

There are a lot of people who suffer from Raynaud syndrome which affects hands as well as feet. The feeling of cold limbs also can be associated with problems of thermoregulation of organism.





There are two places come into consideration according to the venous system of lower limb. The first is at the back part of ankle above the heel and the other is instep feet.

10. TESTING THE EFFECTIVENESS OF PROTOTYPES

10.1. Experiment by thermocamera – indoor conditions

For the final testing will be used the thermal imagining camera again.

The purpose is to determine which prototype can better fulfil the requirement for heating hand without necessity of complete coverage of hand surface.

On the following pictures you can see the differences between the temperature of hand before wearing the mitten/bracelet and after. In the same ambient condition we scan the hand of the same person wearing the bracelet and mitten after 5 minutes, 10 minutes and finally 20 minutes.

This illustration should help us to determine the effectiveness of prototypes by comparing the temperatures in different parts of the hand, as you can see on the following tables 5 and 6.

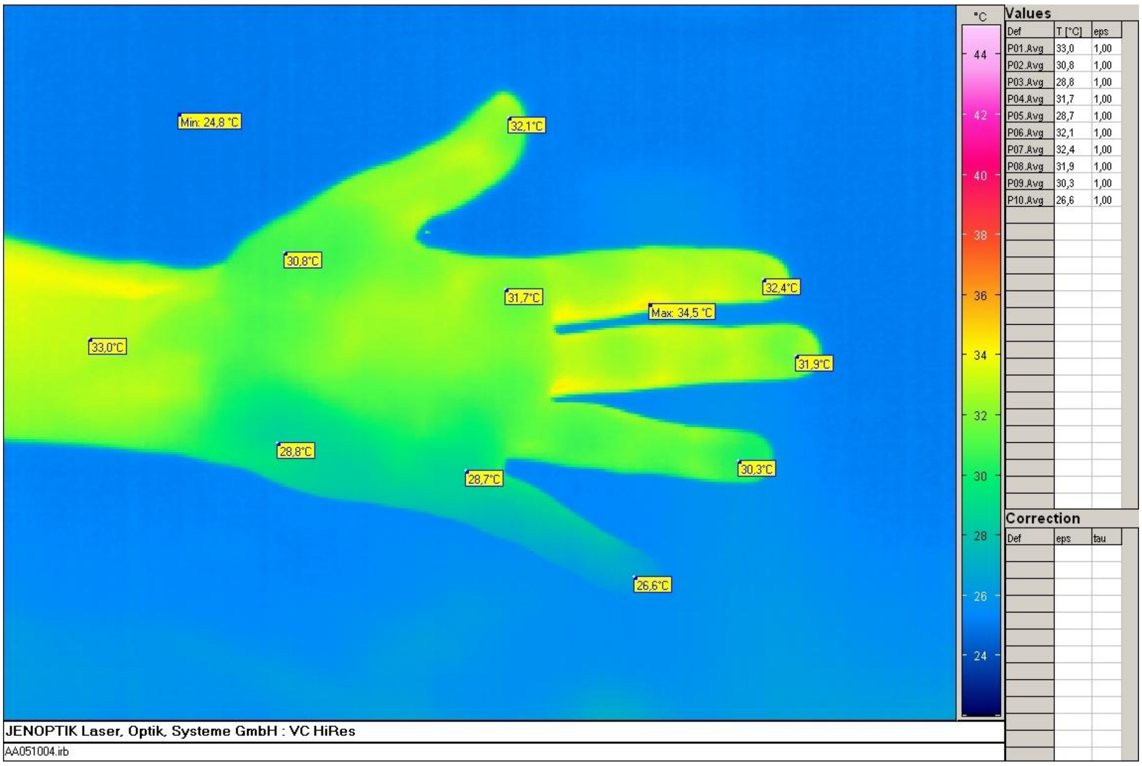


Figure 45: Naked hand scanned by thermocamera

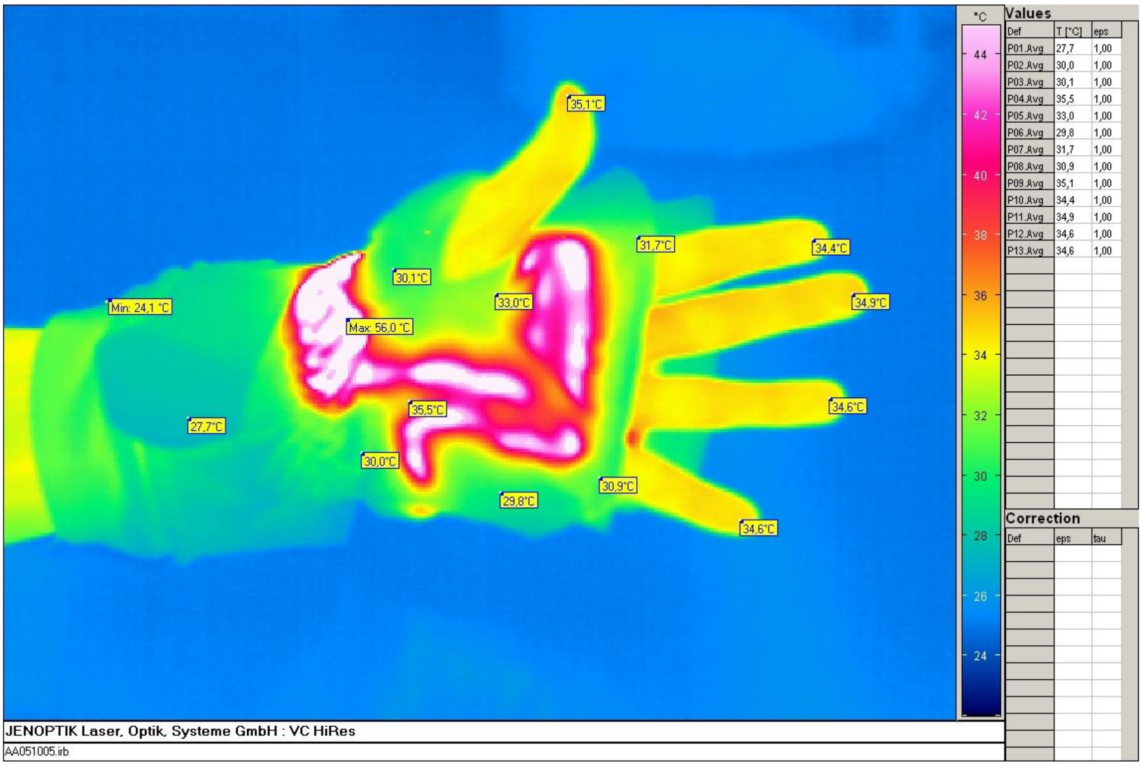


Figure 46: Hand in fingerless mitten after 5 minutes scanned by thermocamera

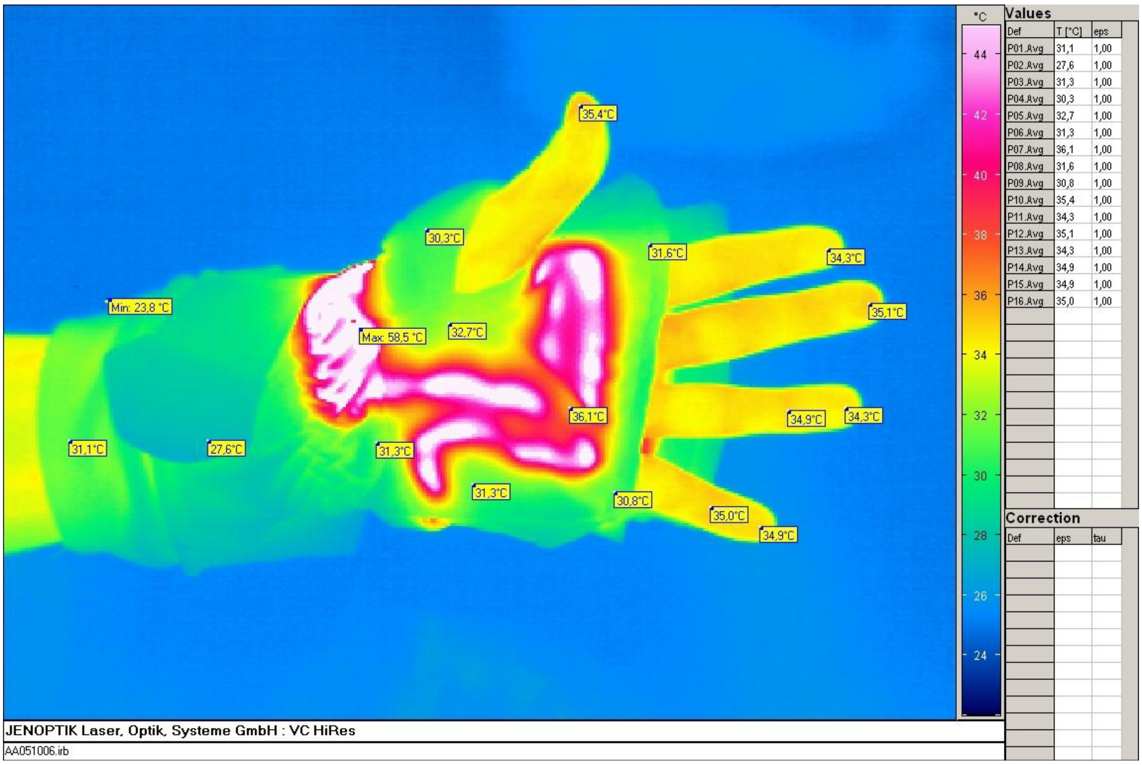


Figure 47: Hand in fingerless mitten after 10 minutes scanned by thermocamera

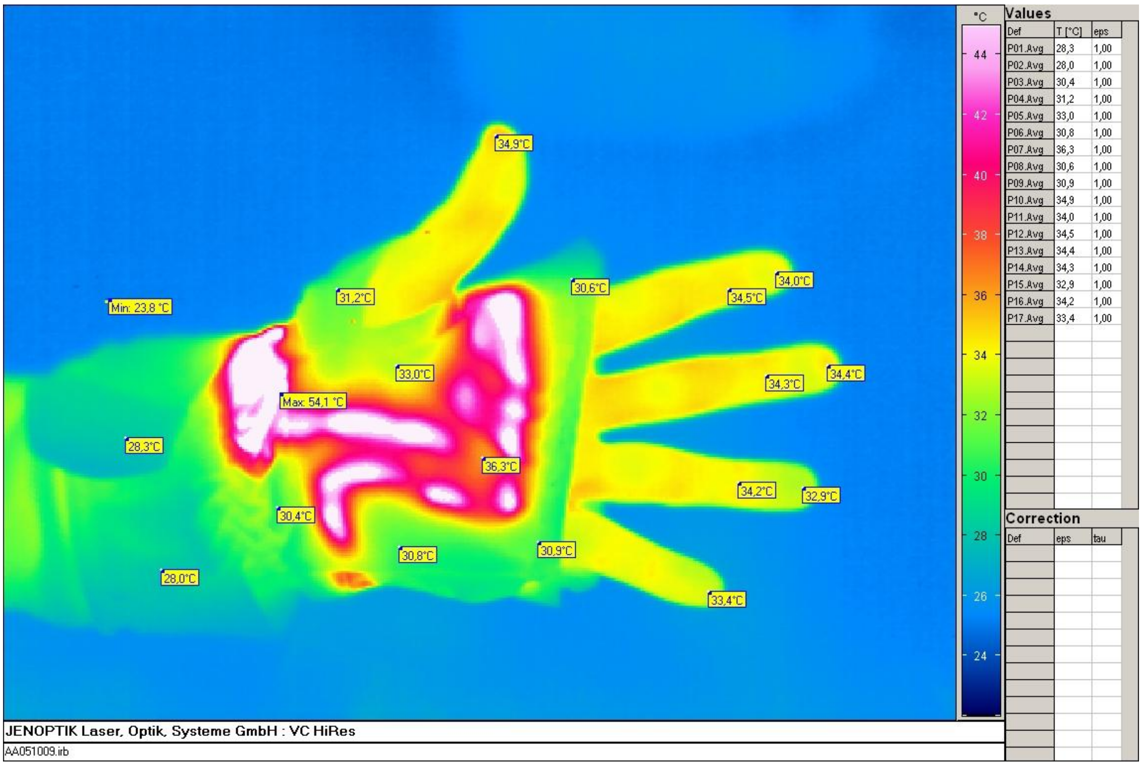


Figure 48: Hand in fingerless mitten after 20 minutes scanned by thermocamera

MITTEN - CHANGES IN FINGER TEMPERATURE [°C]					
	naked hand (0)	5 min	10 min	20 min	increase ºC
THUMB	32,1	35,1	35,4	34,9	2,8
FOREFINGER	32,4	34,4	34,3	34,0	1,6
MIDDLE FINGER	31,9	34,9	35,1	34,4	2,5
RING FINGER	30,3	34,6	34,3	32,9	2,6
LITTLE FINGER	26,6	34,6	34,9	33,4	6,8
					3,3

Table 6: Mitten - changes in finger temperatures [°C]

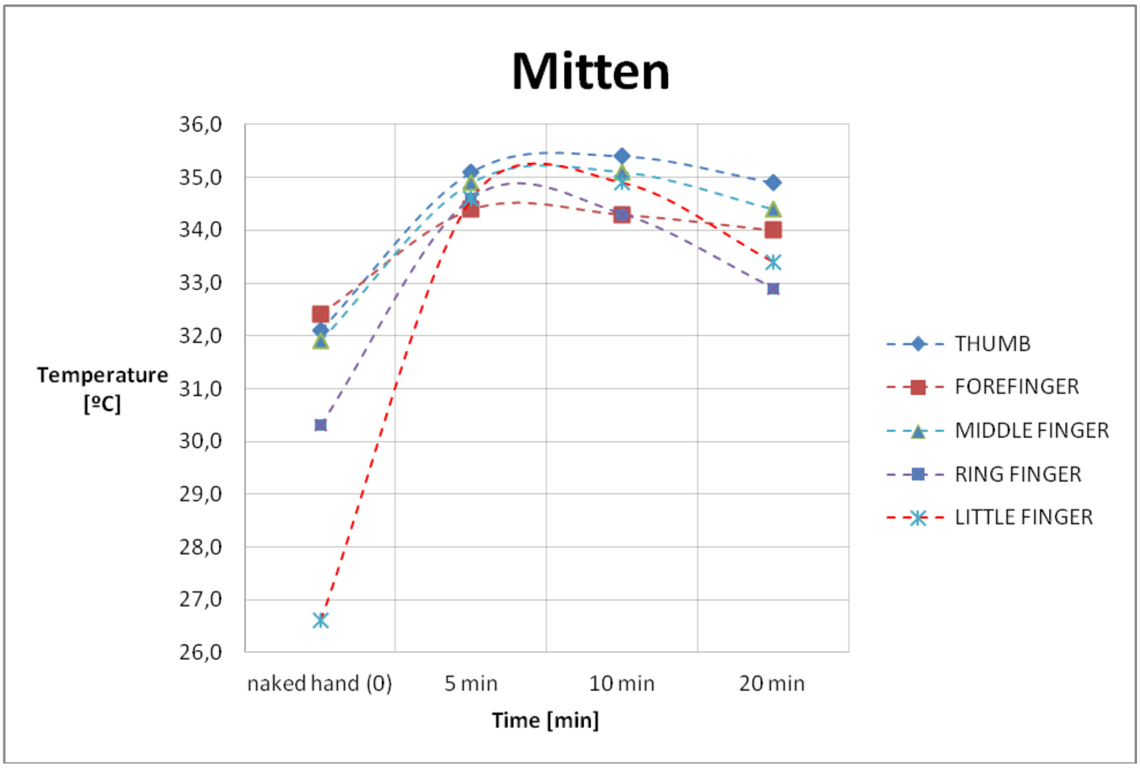


Figure 49: Mitten - changes in finger temperatures [°C]

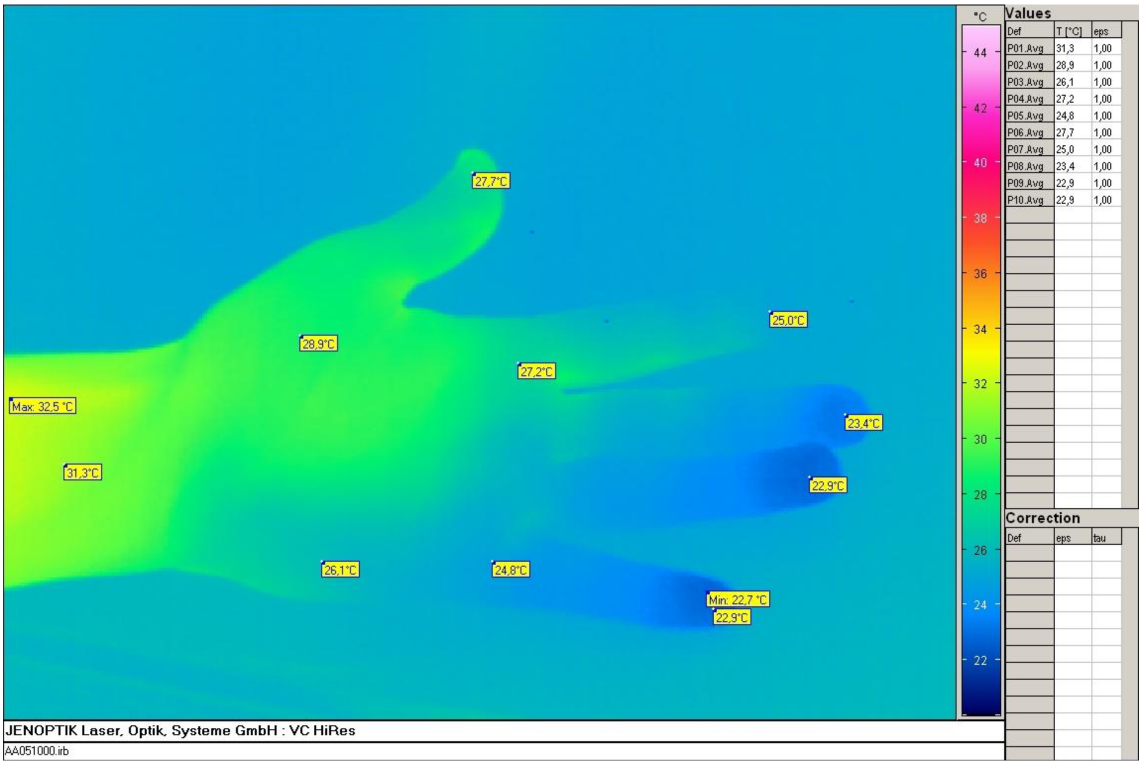


Figure 50: Naked hand scanned by thermocamera

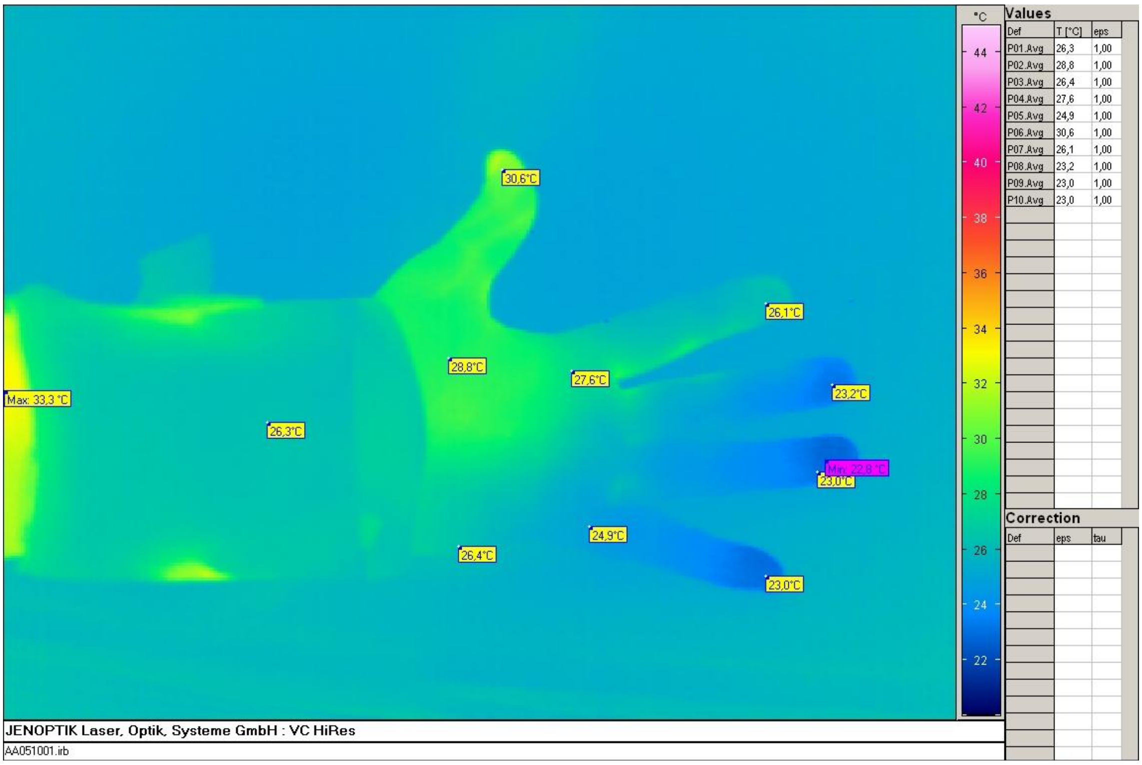


Figure 51: Hand with bracelet after 5 minutes scanned by thermocamera

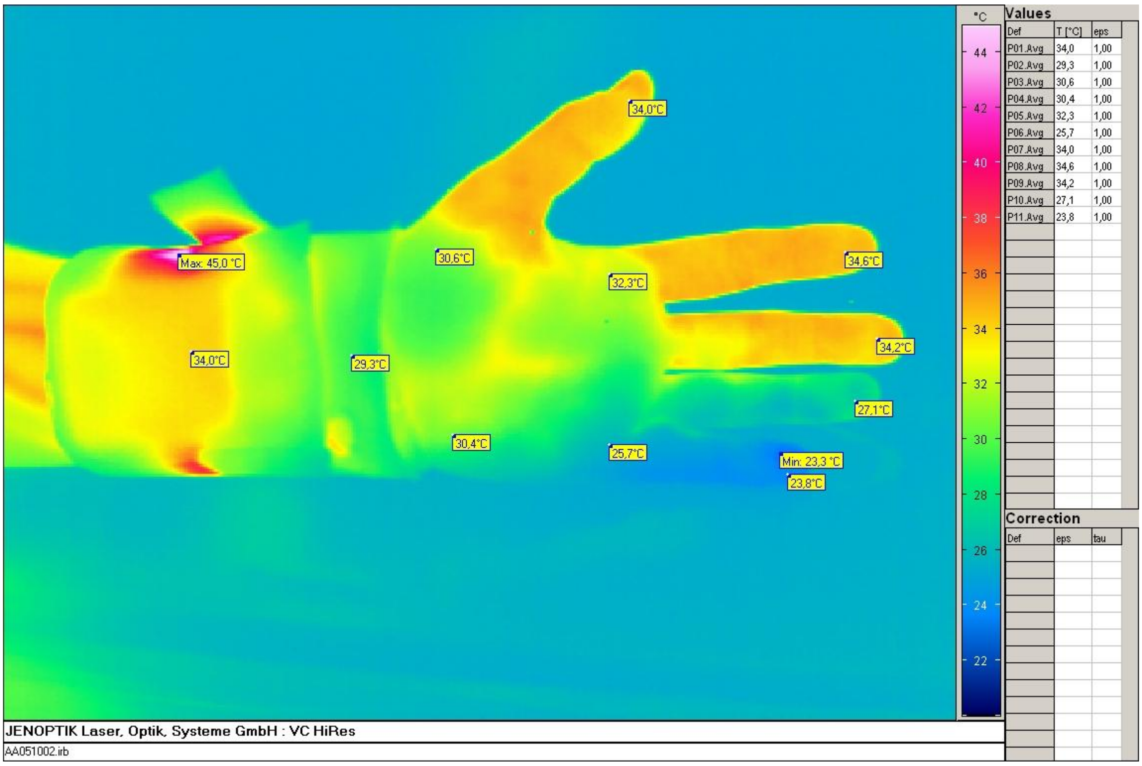


Figure 52: Hand with bracelet after 10 minutes scanned by thermocamera

Figure 53: Hand with bracelet after 20 minutes scanned by thermocamera

BRACELET - CHANGES IN FINGER TEMPERATURE [°C]					
	naked hand (0)	5 min	10 min	20 min	increase ºC
THUMB	27,7	30,6	34,0	33,8	6,1
FOREFINGER	25,0	26,1	34,6	33,4	8,4
MIDDLE FINGER	23,4	23,2	34,2	30,6	7,2
RING FINGER	22,9	23,0	27,1	25,7	2,8
LITTLE FINGER	22,9	23,0	23,8	23,2	0,3
					5,0

Table 7: Bracelet - changes in finger temperatures [°C]

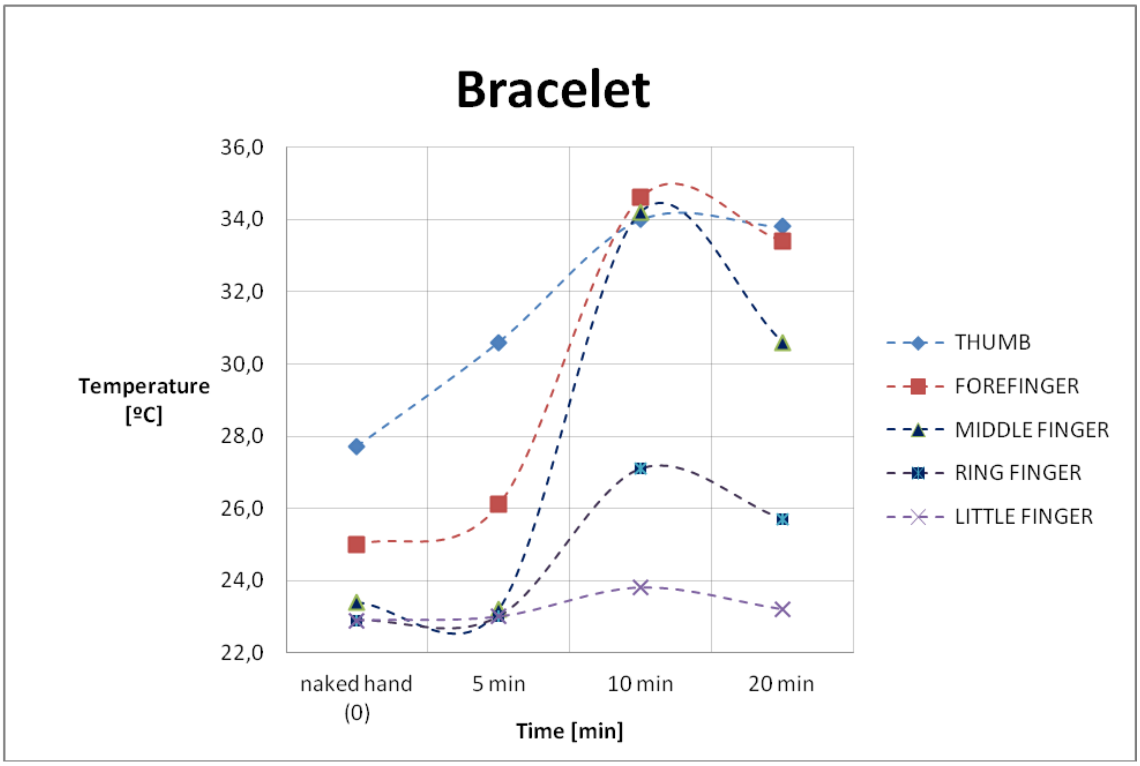


Figure 54: Bracelet - changes in finger temperatures [°C]

10.1.1. Partial conclusion I:

Difficulties of measuring by thermal camera are in adjustment the temperature and color range as well as correct emissivity, which is specific for each material. The value of emissivity of human skin is 0, 98.We need to focus on the correct setting to avoid measuring inaccuracy.

As you can see on the first picture with naked hand, this person suffer from one type of Raynaud´s syndrome. The main health problem is significant especially in little finger, which exhibits much lower temperature than other fingers.

Eventhough the tables show more increases in temperature in bracelet in general, if we go through the numbers in detail, we can come to another conclusion.

The bracelet is able to obtain higher temperature on smaller area, but on our examined person was not functional to increase temperature in fingers with vascular disease. The sufficient increase was obtained in thumb, fore finger and middle finger, but the other two stayed more or less at the same temperature level.

On the other hand, the mitten reaches lower temperature around the hand, so it affects a larger area. For this concrete examined person, this prototype was more suitable. On average the increase of temperatures was just 3,3 °C, but the mitten are able to heat equally all fingers, including the little finger.

10.2. Experiment by temperature sensor Almemo – outdoor conditions

Figure 55: Thermal sensor ALMEMO

Figure 56: Measurement of the middle finger temperature

10.2.1. Ambient temperature -0, 6°C

Temperature in 0 min is the temperature on the middle finger after 20 minutes outside in ambient temperature with the uncovered hand

BRACELET		
time [min]	temperature on the middlefinger [°C]	increase [°C]
0	12,2	
5	14	1,8
10	19,3	5,3
20	24,5	5,2
		12,3

Table 8: Measured on woman 24 years old

ambient temperature [°C]	-0,6
palm temperature after 20 minutes [°C]	24,5
wrist temperature under bracelet after 20 min [°C]	40,5

FINGERLESS GLOVES		
time [min]	temperature on the middlefinfer [°C]	increase [°C]
0	11,8	
5	14,5	2,7
10	19,2	4,7
20	24,2	5
		12,4

Table 9: Measured on woman 24 years old

ambient temperature [°C]	-0,6
palm temperature after 20 minutes [°C]	33,3
temperature at the back of the hand after 20 min [°C]	31,2

temperature around the fingers in the closed glove [°C]	22,6 °C

10.2.2. Ambient temperature 10, 4°C

Temperature in 0 min is the temperature on the middle finger after 20 minutes outside in ambient temperature with the uncovered hand

BRACELET		
time [min]	temperature on the middlefinger [°C]	increase [°C]
0	16,4	
5	16,6	0,2
10	17,7	1,1
20	18,3	0,6
		1,9

Table 10: Measured on woman 25 years

BRACELET		
time [min]	temperature on the middlefinger [°C]	increase [°C]
0	13,3	
5	14,4	1,1
10	15,3	0,9
20	16,9	1,6
		3,6

Table 11: Measured on man 29 years old

BRACELET		
time [min]	temperature on the middlefinger [°C]	increase [°C]
0	14,9	
5	15,4	0,5
10	16,2	0,8
20	16,5	0,3
		1,6

Table 12: Measured on woman 57 years old

BRACELET		
time [min]	temperature on the middlefinger [°C]	increase [°C]
0	27	
5	30,2	3,2
10	31,3	1,1
20	32,1	0,8
		5,1

Table 13: Measured on man 60 years old

FINGERLESS GLOVES		
time [min]	temperature on the middlefinfer [°C]	increase [°C]
0	19,5	
5	19,7	0,2
10	21,4	1,7
20	25,3	3,9
		5,8

Table 16: Measured on woman 25 years old

FINGERLESS GLOVES		
time [min]	temperature on the middlefinfer [°C]	increase [°C]
0	14,0	
5	14,8	0,8
10	15,2	0,4
20	15,2	0
		1,2

Table 17: Measured on man 29 years old

FINGERLESS GLOVES		
time [min]	temperature on the middlefinfer [°C]	increase [°C]
0	14,4	
5	16	1,6
10	16,1	0,1
20	15,6	-0,5
		1,2

Table 14: Measured on woman 57 years old

FINGERLESS GLOVES		
time [min]	temperature on the middlefinfer [°C]	increase [°C]
0	29,0	
5	29,5	0,5
10	32,0	2,5
20	32,3	0,3
		3,3

Table 15: Measured on man 60 years old

The numbers in yellow cells indicating the temperature change between the initial (time 0 - naked hand without heating) and hand after 20 minutes of heating to see the total change during the process.

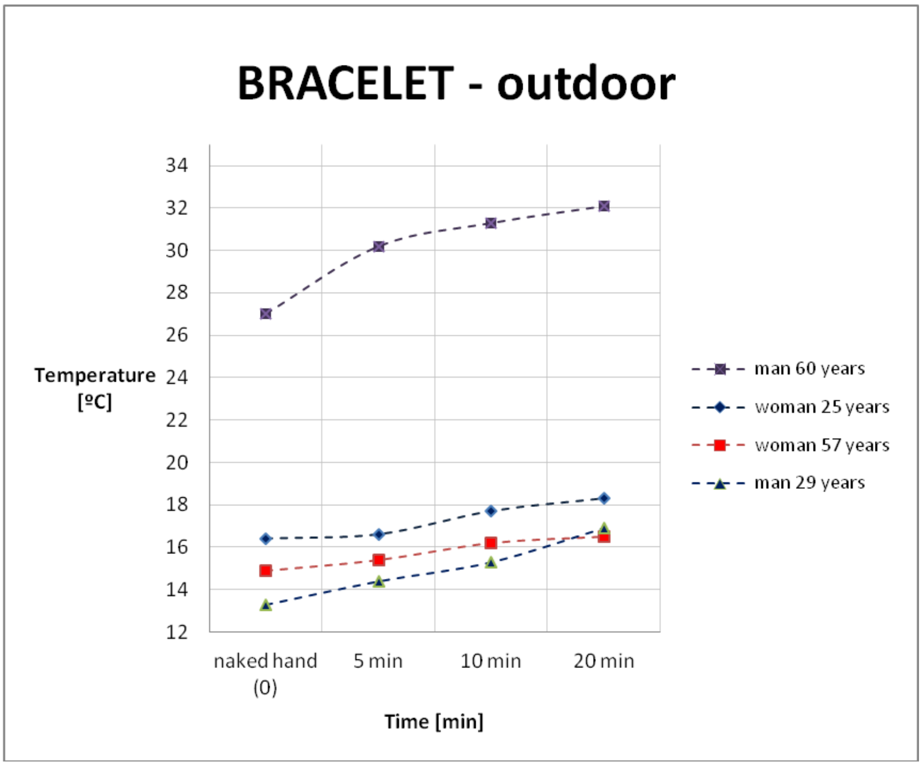


Figure 57: Bracelet test outdoor - changes in middle finger temperatures [°C]

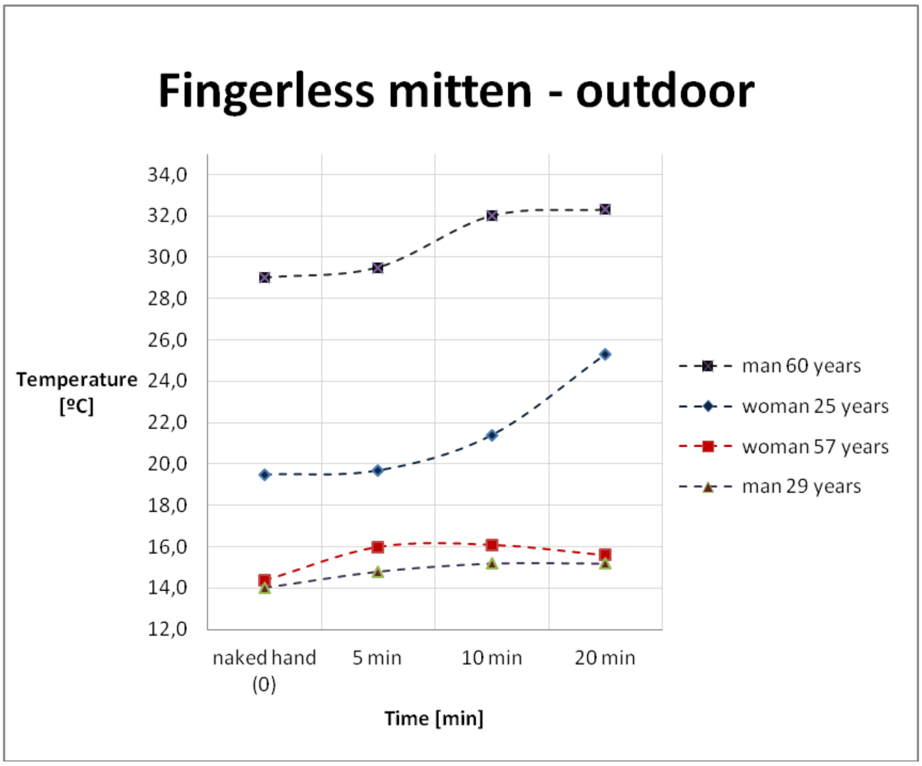


Figure 58: Mitten test outdoor - changes in middle finger temperatures [°C]

10.2.3. Partial conclusion II

This part of testing was taken outside, using the temperature sensor Almemo. We can say, in general, the measurement with the temperature sensor is more accurate than the measurement with thermocamera, which can be affected by couple of ambient conditions.

There is one fact really obvious. Finger temperature increase is higher, the lower is the initial temperature of them. The reason is human body thermoregulation. In colder ambient the body is under threat and the inner temperature is reduced. Body uses thermoregulation to reach the optimal temperature again and the prototypes heating feature helps body to stabilize the correct temperature faster.

Our measurements were taken on 4 people – 2 men and 2 women - in different ages. The measured values followed to decision to leave out statistics and all generalization. Functionality of the device depends on many factors, which cannot be demonstrated statistically. The factors are age, health, physical and psychical condition, metabolism, gender and so on.

There is a photo demonstrating different hand temperature of woman and man in general. (APPENDIX 4) It is well known fact that women suffer from cold hand more often than men. On the top of that, woman temperature is changing during a month due to hormonal changes. [18]

CONCLUSION:

There are a lot of people suffering from cold hands during outdoor activities as well as people who suffer from “cold hands” as vascular disease, e.g. Raynaud´s syndrome.
The main idea of this thesis was to test if it is possible to keep warm unprotected fingers heating wrist or/and palm. We assume, that, if is possible to increase the temperature of blood in the two major arteries, the passing blood will heat also the unheated fingers.

Skin temperature under normal conditions has approximately 32ºC. Feelings of pain appear when the skin temperature is more than 43ºC or less than 15ºC. [18]

The final product of this project is in shape of bracelet and fingerless gloves. Final prototype is a result of combination of textile and electronic components.

For the *prototype 1* we decided to remake usual mittens for sport. These gloves can be used in two ways:

> The first is usual shape of mittens. The heating system can heat the hand running on battery hidden on wrist pocket and the warm air can circulate inside the mittens around fingers and palm.
>
> Other way is to open the top parts of gloves which cover fingers and thumb. The heating system can still work and fingers can be used without any restrictions for any work or activity. In case of unpleasant cold in fingers, the mitten can be closed again using the simple system of Velcro.

There was created another prototype, reference as *prototype 2* in shape of bracelet with mobile thermal pad. This prototype corresponds more to the original idea. The heating pad is placed in the inner pocket made from netting fabric and is in direct contact with the wrist part where the main arteries passing. It means the warm is concentrated at the limited area.

The heating system of the prototypes (composed of the 3,7V battery and network from twisted copper yarn) can works for the duration of 2 hours and 20 minutes at continuous operation. The length of wire is still the same in both prototypes - 1m, but the difference is in the size of the area covered by the system. The bracelet is able to obtain higher temperature on smaller area. On the other hand, the mitten reaches lower temperature around the hand, so it affects a larger area.

The purpose was to compare these two prototypes. Each has its own conveniences as well as inconveniences.

Prototype 1: The mittens

+ Can be used as usual mittens or as fingerless gloves depend on the situation and on actual feeling

+ They are very comfortable for wearing.

- It is impossible to remove the heating system which can cause some problems with washing. The only removable part is the battery from wrist pocket.

Prototype 2: The bracelet

+ All electronic parts can be taken out what make the bracelet able to wash as often as necessary

+ There is wider variability of use, for example to lower limb or another part of body

- The heat affect just a small limited area of skin, thus the instantaneous temperature is higher (going to more than 40 degrees) what becomes unpleasant after some time.

Both the prototypes were consulted with MUDr. Marie Pometlová from Third Faculty of Medicine of Charles University, Department of Normal, Pathological and Clinical physiology in Prague.

She has provided her final opinion from the aspect of healthcare. According to her conclusion, more suitable seems to be the first prototype - Mitten. They are multifunctional and the user is able to adjust the most pleasant temperature for him by opening or closing the system. The bracelet is more radical modification of heated gloves, but the heat is concentrated on a small area, thus the higher temperature

in long-term using can cause health problems, as multiplication of bacteria, inflammation or even skin burns of more sensitive human. The solution can be incorporated thermoregulation into the prototype.
From her point of view, this product would appreciate especially people suffering from Raynaud´s syndrome, because it can help to prevent attacks of diseases which come already at temperatures around 10 degrees.

The prototypes were tested by thermocamera and by the temperature sensor. Functionality of the prototypes depends on many factors, which cannot be demonstrated statistically. The factors are age, health, physical and psychical condition, metabolism, gender and so on.

The most important inconvenience of our prototypes is the heating solution using the copper wires. In case of stronger material stress or folding it is very likely to break the copper wire and thus break the circuit, which stops heat up. The most critical is the connecting point to the battery. It means this solution is not very durable but for our purpose it is sufficient. In practice life it is necessary to use more resistant material. We tried to suggest other possible solutions in part of APPENDIX 5 and 6 of this thesis.

Competition in the sector of heated equipment is extremely high and it is very difficult to come with completely different type of product to the market. In the case of our prototype is hard to say, if it can succeed in compete with other producers, but still it is a product that fulfils its function.

The patent application of heating fingerless gloves using the heating of circulated blood for thermoregulation of fingers is preparing.

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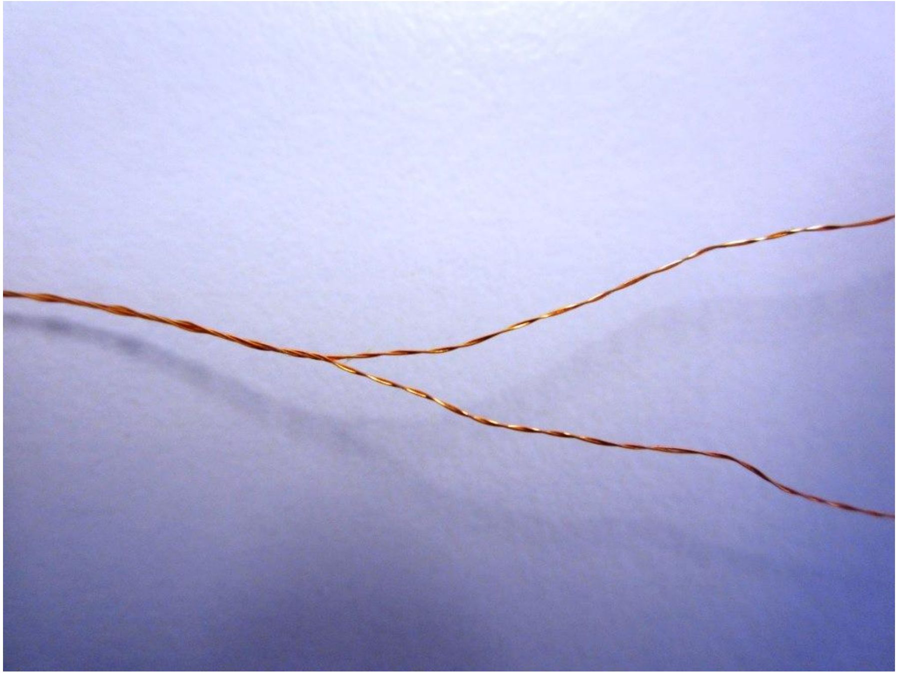
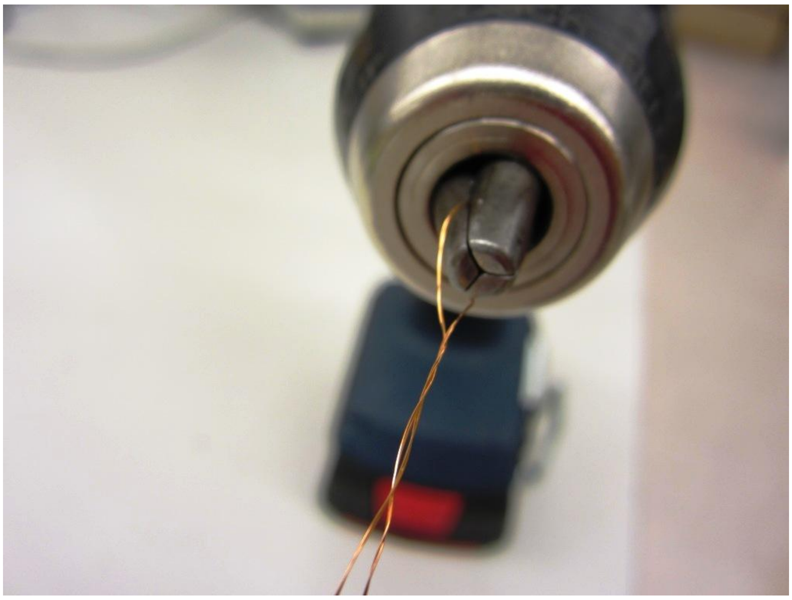
APPENDIX 1: TohoTenax Europe GmbH - product sheet of carbon yarns

Brand name	Production site	Fiber family & tensile properties	Sizing properties	Number of filaments	Nominal linear density (without sizing)	Additional information	Tensile strength [MPa]	Tensile modulus [GPa]	Elongation at break [%]	Filament diameter [µm]	Density [g/cm³]	Sizing	Size level [%]
Tenax®-J		HTA40	H15	1K	67tex	15S	3950	238	1.7	7.0	1.76	EP	2.5
Tenax®-J		HTA40	F15	1K	67tex	15S	3950	238	1.7	7.0	1.76	PU	2.5
Tenax®-J/E		HTA40	E13	3K	200tex		3950	238	1.7	7.0	1.76	EP	1.3
Tenax®-E		HTA40	E13	3K	200tex	15Z	3950	238	1.7	7.0	1.76	EP	1.3
Tenax®-J/E		HTA40	E13	6K	400tex		3950	238	1.7	7.0	1.76	EP	1.3
Tenax®-E		HTA40	E13	6K	400tex	10Z	3950	238	1.7	7.0	1.76	EP	1.3
Tenax®-E		HTS40	F13	12K	800tex		4300	240	1.8	7.0	1.77	PU	1.0
Tenax®-E		HTS40	F13	12K	800tex	10Z	4300	240	1.8	7.0	1.77	PU	1.0
Tenax®-E		HTS45	E23	12K	800tex		4500	240	1.8	7.0	1.77	EP	1.3
Tenax®-E		HTS40	F13	24K	1600tex		4300	240	1.8	7.0	1.77	PU	1.0
Tenax®-E		HTS40	F13	24K	1600tex	5Z	4300	240	1.8	7.0	1.77	PU	1.0
Tenax®-J/E		STS40	F13	24K	1600tex		4000	240	1.7	7.0	1.77	PU	1.0
Tenax®-J/E		STS40	F13	48K	3200tex	CP	4000	250	1.6	7.0	1.77	PU	1.0
Tenax®-J		UTS50	F13	12K	800tex		4800	240	2.0	7.0	1.79	PU	1.0
Tenax®-J		UTS50	F24	24K	1600tex	D	5000	245	2.1	7.0	1.79	PU	1.6
Tenax®-J		IMS60	E13	24K	830tex		5700	290	1.9	5.0	1.80	EP	1.3
Tenax®-E		IMS65	E23	24K	830tex		6000	290	1.9	5.0	1.78	EP	1.3
Tenax®-J		UMS40	F23	24K	800tex		4600	395	1.2	4.8	1.79	PU	1.0
Tenax®-J		UMS45	F22	12K	385tex		4600	430	1.1	4.7	1.81	PU	0.8
Tenax®-J		HTS40	A23	12K	1420tex	MC	2750	215	1.2	7.5 *	2.70	PU	1.3

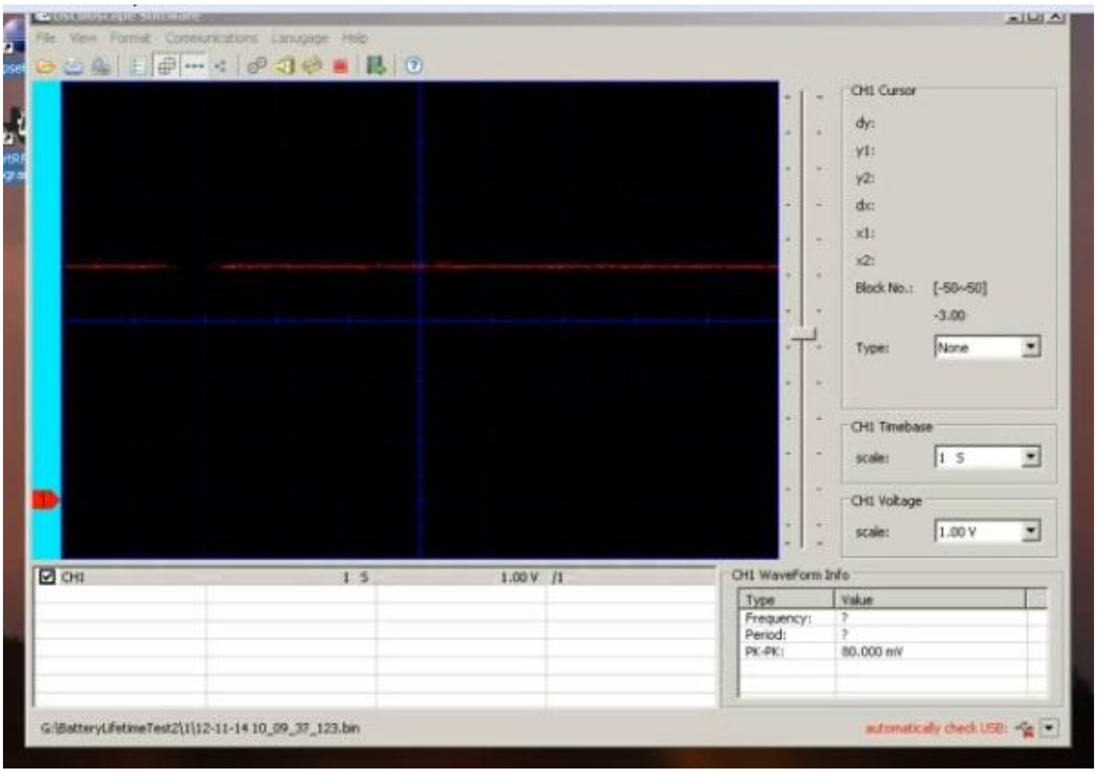
* incl. 0.25 µm Nickel

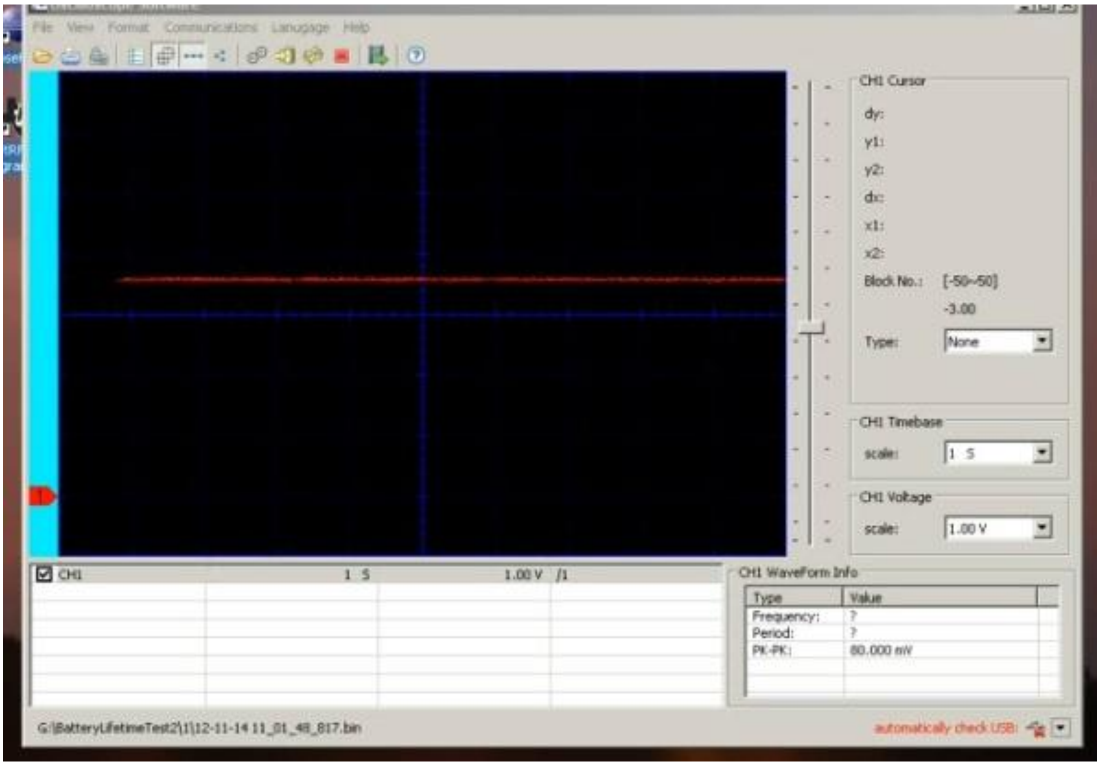
APPENDIX 2: Twisted copper wire

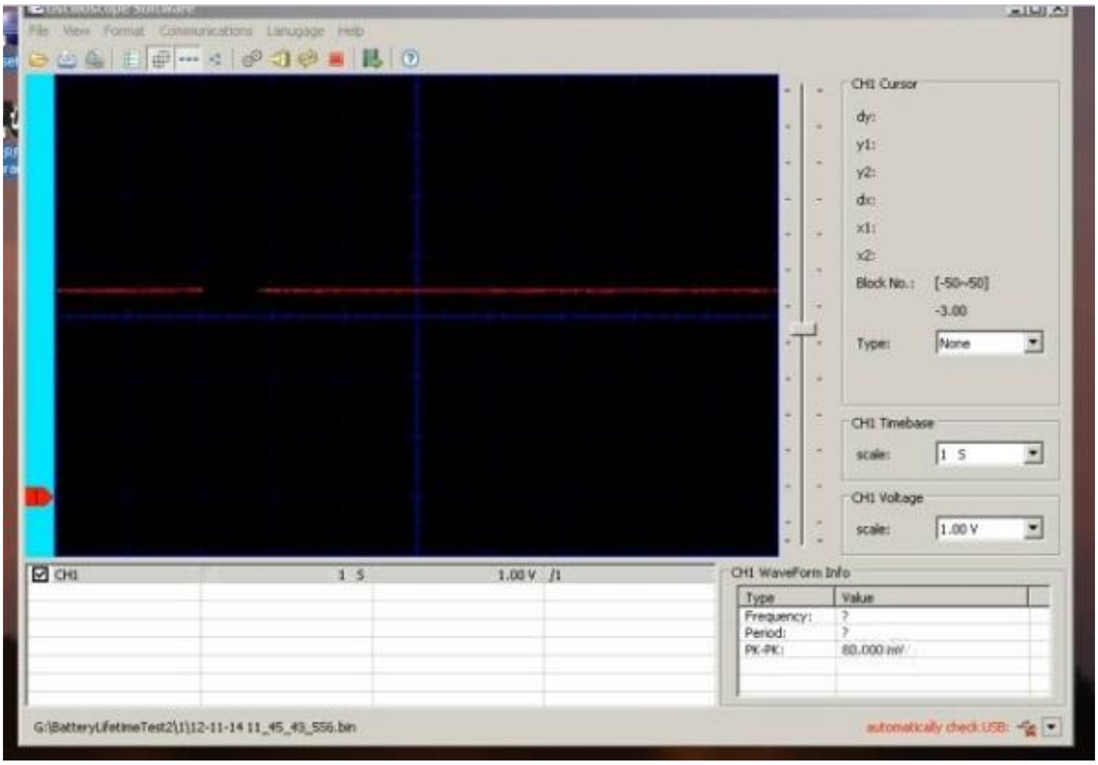


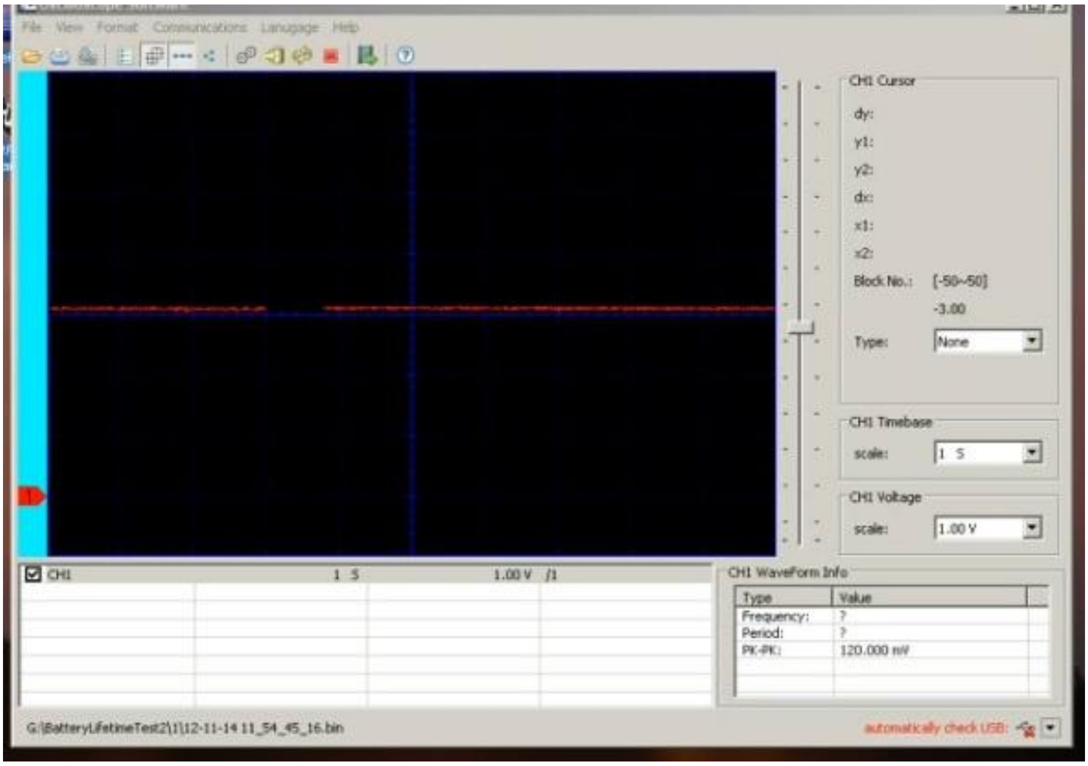


APPENDIX 3: Lifetime of the battery connected with our resistive wire scanned by oscilloscope






File View Format Communications Lanugage Help
CH1 Cursor
dy:
y1:
y2:
dx:
x1:
x2:
Block No.: [-50~50]
-3.00
Type: None
CH1 Timebase
scale: 1 S
CH1 Voltage
scale: 1.00 V
CH1 1 S 1.00 V /1
CH1 WaveForm Info
Type Value
Frequency: ?
Period: ?
PK-PK: 80.000 mV
G:\BatteryLifetimeTest2\1\12-11-14 11_45_43_556.bin
automatically check USB:


File View Format Communications Lanugage Help
CH1 Cursor
dy:
y1:
y2:
dx:
x1:
x2:
Block No.: [-50~50]
-3.00
Type: None
CH1 Timebase
scale: 1 S
CH1 Voltage
scale: 1.00 V
CH1 1 S 1.00 V /1
CH1 WaveForm Info
Type Value
Frequency: ?
Period: ?
PK-PK: 120.000 mV
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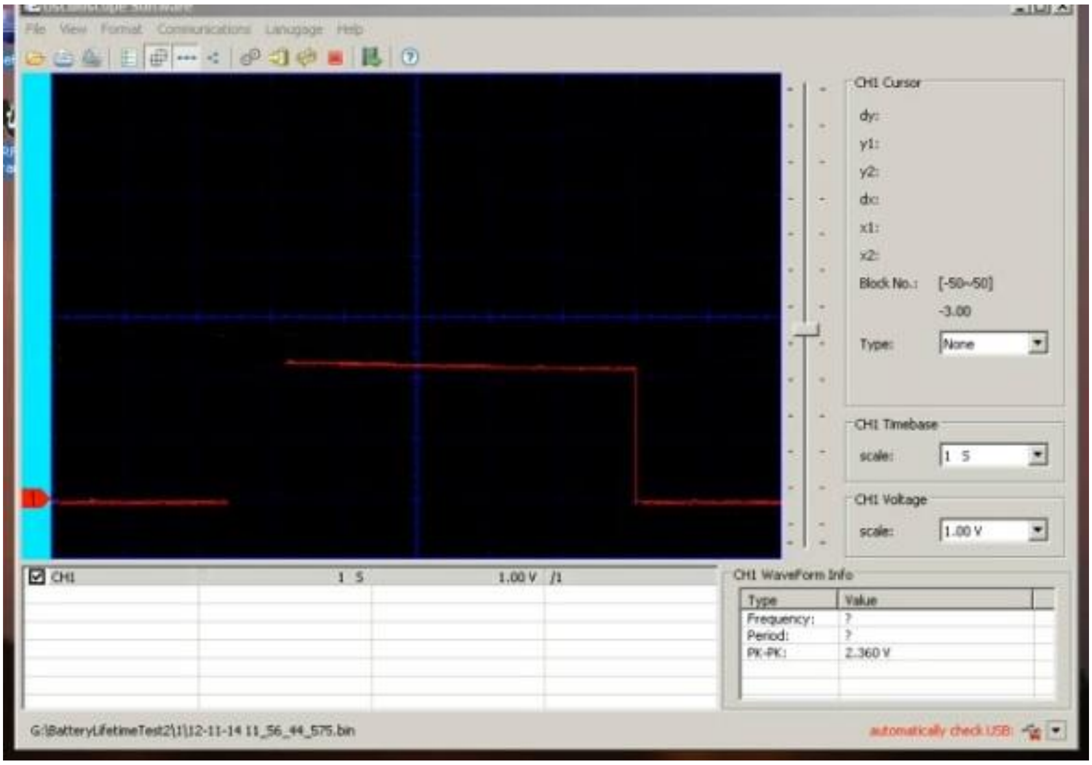
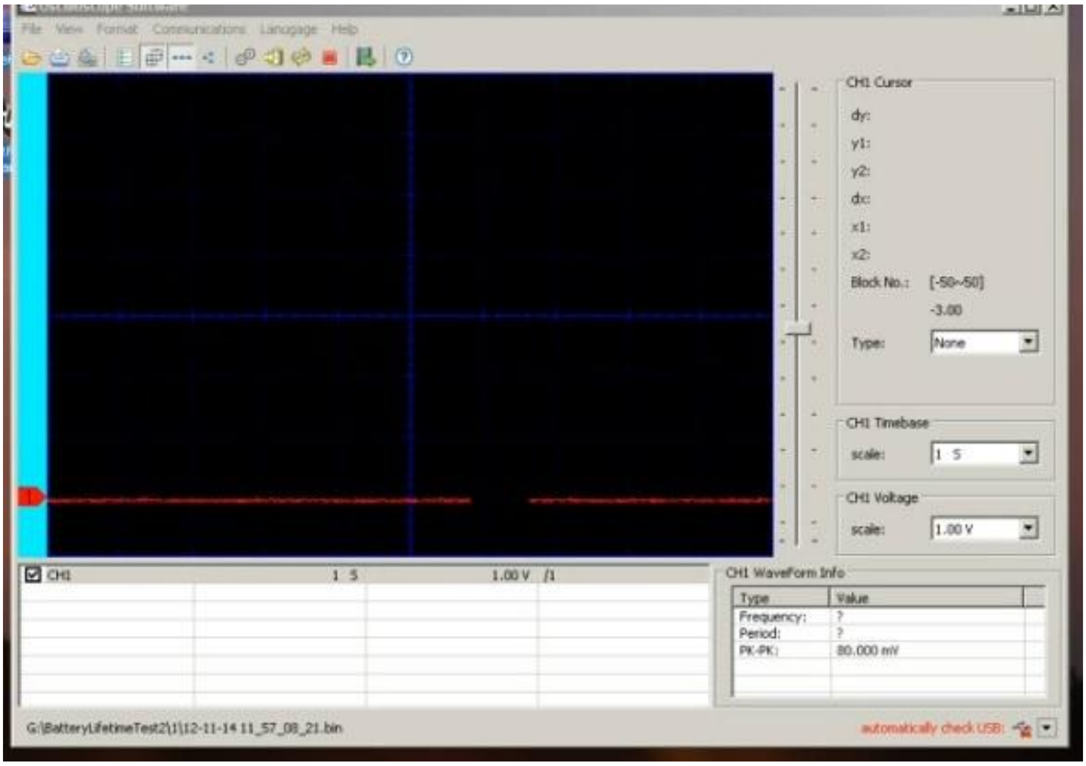
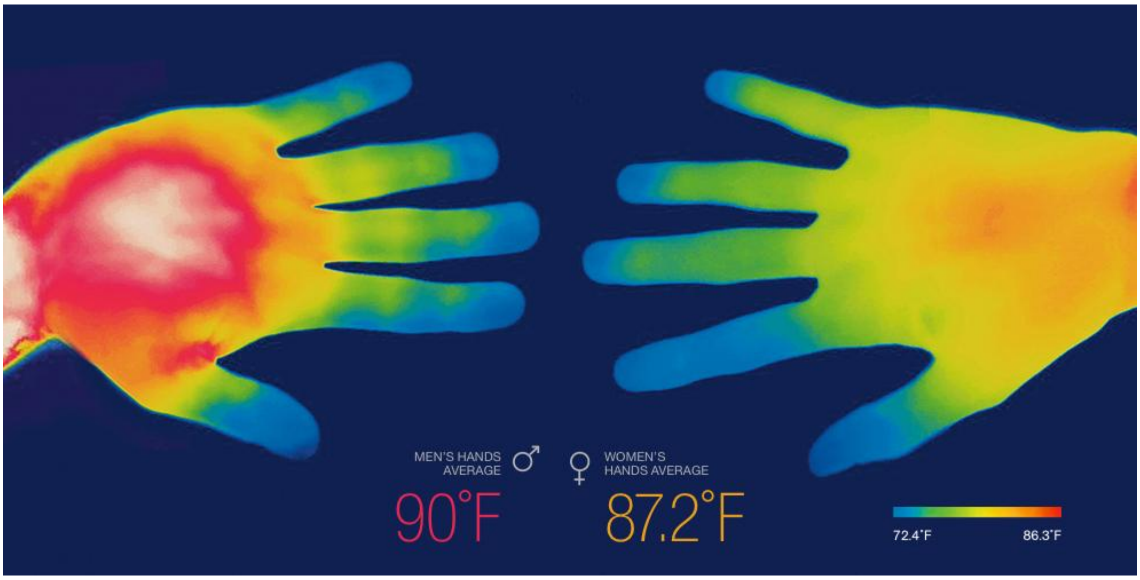
automatically check USB:





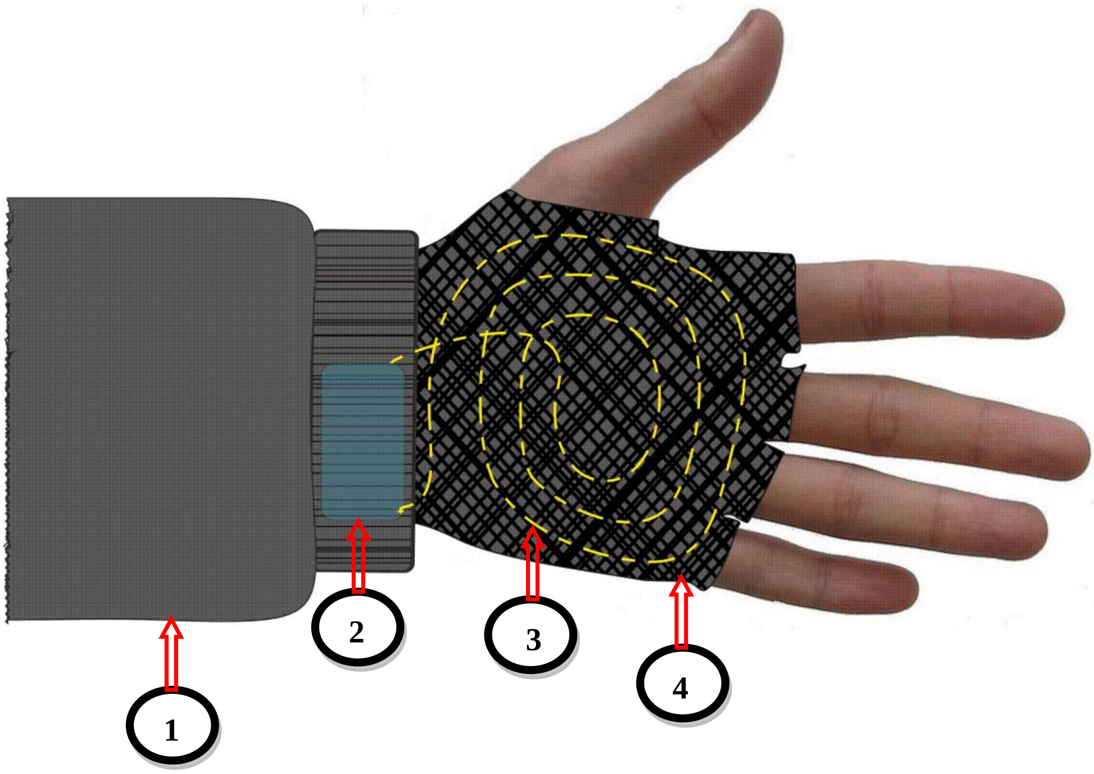
The photos are taken at 25 minute intervals. You can see the decline of voltage during the lifetime of battery.

APPENDIX 4: thermal photo shows a woman's hand cooler than a man's hand. [16]



Men:	*90°F*	*= 32,222 °C*
***Women**:*	*87,2°F*	*= 30,667 °C*

APPENDIX 5: Design of alternative prototype with resistive wire



1 . . . jacket sleeve

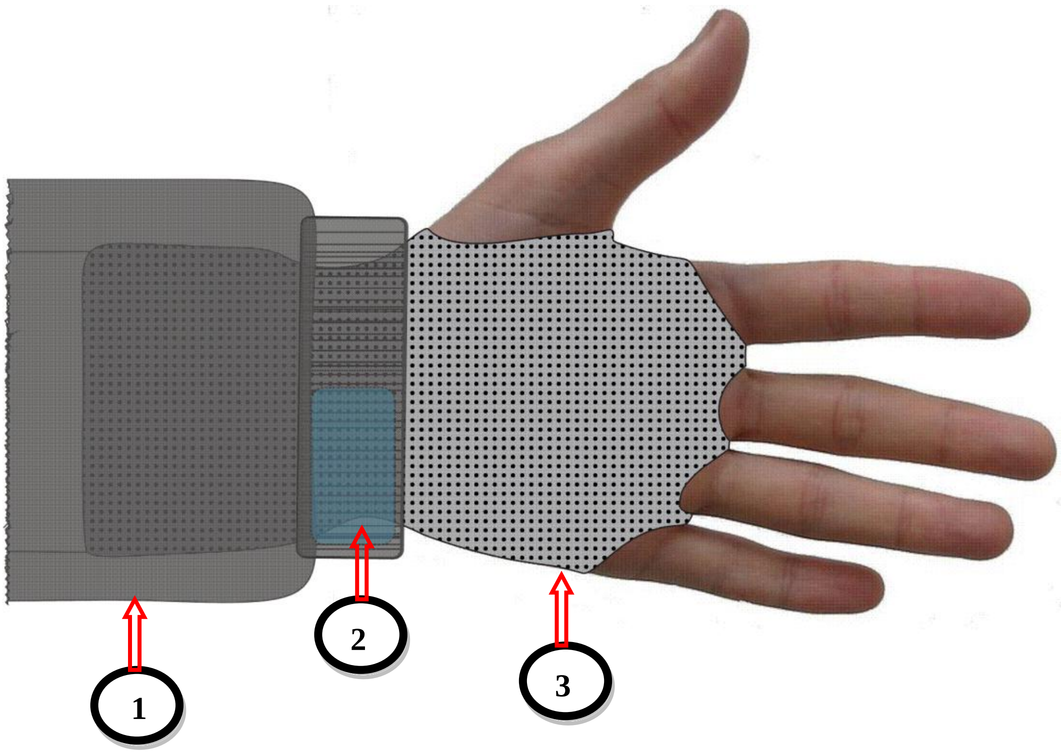
2 . . . battery

3 . . . resistive wire (e.g. stain steel)

4 . . . knitted tubing

Previous picture shows alternative design solution, using the same thermo physical effect as the previous prototypes. The knitted tube is a part of wrist cuff, so that the customer does not need separate glove or other item to use the heated wire. It can be already a part of the jacket sleeve with the pocket for battery included in the cuff.

APPENDIX 6: Design of alternative prototype with heated polymer "FabRoc"



1 . . . jacket sleeve
2 . . . battery
3 . . . heated polymer "FabRoc"

The other picture shows alternative design solution, using the special heated polymer FabRoc, mentioned at the beginning of the thesis in part of STATE OF ART. The convenience is very good mechanical resistance, which allow using it as tube covering wrist and also palm and back of hand heating in the whole surface around. It can be also a part of the jacket sleeve.